Technical Report

SNOW MANAGEMENT

Snow Management Techniques for Mined-Land Reclamation

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

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16. Abstract (Limit: 200 words)

Highway departments, railroads and ranchers have been managing snowdrifts for many years. Agricultural researchers over the past twenty years have been developing exciting techniques for trapping windblown snow, improving soil water and increasing crop yields.

[illegible] this report an attempt is made to apply existing knowledge of snow management techniques to the problem of mined-land reclamation. Many surface mines and potential mineral leasing areas are located in semiarid areas where vegetation is risky. Management of blowing snow to increase plant-available water in reclamation sites offers considerable promise.

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SNOW MANAGEMENT POTENTIAL ON SURFACE-MINED AREAS;

REVIEW OF TECHNIQUES AND ASSESSMENT OF DATA NEEDS

A Study Proposal

for Consideration of Funding under

EMRIA in Fiscal Year 1979 in

Response to Requests by Montana,

Wyoming and Colorado State Offices

by

Dr. H. Steppuhn (Project Leader)
Dr. D.M. Gray (Co-investigator) Chairman of
Division of Hydrology
University of Saskatchewan
Saskatoon, Saskatchewan
Canada

April, 1979

TITLE: Snow Management Potential on Surface Mined Areas; Review of Techniques and Assessment of Data Needs.

SYNOPSIS: Snowcover manipulation techniques have been developed and studied by researchers, primarily for agricultural and hydrological situations. However, the available information on snow management has never been collated and summarized in a source document having specific application to the problem of mined-land reclamation. Effective snowcover management can be used: to increase soil water, to reduce wind-caused soil erosion, and to improve plant-water relations on revegetated areas. The proposed study will review and evaluate snow management techniques and suggest applications to mined-land reclamation and present these findings in a document for use by the Bureau. Such information would be used, after appropriate training, by the Bureau of Land Management specialist (hydrologist, soil scientist, range ecologist) as an aid in determining reclaimability and reclamation stipulations.

OBJECTIVES:

1. To summarize the application of snowcover manipulation techniques for land management purposes;
2. To review and evaluate snow management techniques with respect to their potential use on surface-mined areas; and
3. To assess data needs and recommend directions for field studies related to snow management on surface-mined lands.

BACKGROUND:

Water is recognized as a major limitation to plant growth throughout the Northern Great Plains. Within this region, the evapotranspiration demand exceeds the growing-season rainfall. A significant portion of the water deficiency, however, is supplied by soil storage of winter snowmelt. Average annual snowfall over the Great Plains ranges from 50 mm water equivalent in Kansas to 130 mm in Saskatchewan and often supplies that critical addition which permits dryland cultivation without irrigation. At the same time, full agricultural benefits from snow are commonly diminished or lost by management practices which allow or promote redistribution by wind. Wind carries particles of snow from fields and pastures and deposits them in road ditches, ravines, hedgerows, and other leeward site positions.

Numerous studies have related crop yield to soil water availability. Willis and Frank (1975) have even demonstrated a global relationship between snowcover extent and wheat production in the northern hemisphere. Schlehuber and Tucker (1967) not only correlated wheat yield to total available water, but more specifically to that quantity of soil water stored at the time of spring growth following snowmelt. Consequently, any technique which augments the quantity of melted snow entering soil reserves improves its water status, promotes crop growth, and increases productivity.

The management of snowcovers offers a ready potential for increasing available water for cultivated or forage crops in semiarid climates. Within the hydrological cycle, snow represents the only component which can be manipulated without broad-scale alteration of the system, viz, cloud seeding or surface water diversions. That is, an agricultural producer or land manager may manipulate as much or as little landscape as desired to achieve specific, selected

goals. For example, if some soils in a highly productive rangeland were very susceptible to wind erosion, a manager might apply a snow water trapping technique to induce the establishment of a more water-demanding, but soil stabilizing vegetative cover. Pastures in these sites could be seeded with a species combination of tall plants possessing good snow-trapping potential and highly palatable, but more hydrophytic, forages. The characteristics of snow which advantage its conservation by management include: (1) its availability for manipulation while stored above ground, (2) its susceptibility to redistribution by wind, and (3) its compatibility with existing management practices.

Increases in snowcover quantities tend also to recharge soil water to greater depths, thus, allowing establishment of deeper-rooted plants. Tests in Saskatchewan have shown average differences in soil water under snow management in barley fields compared to unmanaged fields of +16% at 15 cm depth, +39% at 30 cm and +226% at 60 cm.

Snowcover management, techniques possess the potential for overcoming, or at least ameliorating, soil water shortages in reclamation projects undertaken within the Northern Great Plains. Consequently, development of these techniques could provide the availability of additional options for land managers and reclamation specialists, especially in projects involving revegetation. Although research pertaining to the shaping of mine spoils to promote snow accumulation has been initiated, the applicability of many other proven snow manipulation techniques have not been reviewed with respect to their application for reclamation purposes. Potential snow management practices fall into four categories (1) snow fencing, (2) terrain shaping, (3) vegetative manipulation, and (4) water harvesting. Obviously, various combinations are possible to achieve a variety of technical objectives and reclamation aims within viable economic levels. It will be the focus of the investigation proposed herein to provide a critique of the various techniques in a reclamation application. Besides presentation of advantages and limitations of the different methods, and an outline of data requirements necessary for the technical selection of suitable management methods, a summary of new, but potentially viable, approaches will be provided.

Dyck, G.E., D. Erickson and H. Steppuhn, 1979. Snow ridging to increase soil water. Proceedings 1979 Soils and Crops Workshop. Extension Division, University of Saskatchewan, Saskatoon.

Schlehuber, A.M. and B.B. Tucker, 1967. Culture of wheat. Chapter 4, in Wheat and Wheat Improvement. K.S. Quisenberry and L.P. Reitz, Editors. Agronomy Series No.13, pp.117-179. Amer. Soc. of Agronomy, Madison, Wisconsin.

Willis, W.O. and A.B. Frank, 1975. Water conservation by snow management in North Dakota. Proceedings Symp. on Snow Management on the Great Plains, Great Plains Agricultural Council Pub. No.73, pp.144-162. Univ. of Nebraska, Lincoln, Neb.

WORK PLAN:

1. Review of existing literature, including translated USSR reports, pertaining to snow management concepts, techniques and current practices.
2. Selected trips to research units, study sites, mining operations and reclamation areas for onsite: (1) appreciation of experimental conditions associated with past and present research and (2) familiarization of proposed environments for snow managment application to reclamation.
3. Evaluation of snowcover management applied to the reclamation of surface-mined lands within:
   (1) short and mid-grass prairie,
   (2) sagebrush and half-shrub types, and perhaps
   (3) aspen-parkland complexes, and
   (4) open pine-park types.
4. Written report on the potential of snow management for the reclamation of surface-mined lands including: (1) a review of current and past research, (2) a brief outline of related management options, and (3) a list of applicable data and study requirements for knowledgeable implementation in practice.
5. Presentation at a seminar of the potentials, limitations, immediate applications, and possible future directions for reclamation-applied snowcover management to appropriate BLM field specialists and managers.

EXPERIENCE (personnel[1])

H. Steppuhn (Ph.D.) Research Scientist, Department of Agricultural Engineering and Division of Hydrology - expertise in surface and land-use hydrology, agricultural snow and water management and snow hydrology. (~10 years experience). Present research efforts are directed to the application of engineering control measures in snow management for agriculture, studies of snow accumulation and distribution including areal measurement and condensation/sublimation losses, and studies of the snowmelt process and the soil water additions by snow.

D.M. Gray (Ph.D.) Professor, Department of Agricultural Engineering and Chairman, Division of Hydrology - wide international reputation and experience in hydrology with emphasis on all aspects of snow hydrology including accumulation, melt, runoff and their physical interrelationships (~18 years experience). Author and Editor-in-chief of "Principles of Hydrology", and currently serving as editor of a Book on Snow and Its Phenomena (~900 pp). Present research includes the landuse influence on snow accumulation, melt processes, and meltwater infiltration. Ability to sort, to collate, and to focus hydrologic information, reports and ideas into applicable principles and useful conclusions for use by management agencies.

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[1] The project participants, H. Steppuhn and D.M. Gray have established national and international reputations in their respective fields of specialization and are the authors of numerous scientific publications. Curriculm Vitae or Personal Data forms on each will be supplied on request.

ESTIMATE OF COSTS:

1. Manpower

   (a) Research Technician (Mr. Eric Johnson)
   - execution of a comprehensive literature search,
   - assistance with computerization of references
   - assistance in report writing

   ~~5 months~~ @ ~~717/mo~~ (US) @ 768.25/mo — $ ~~3486.20~~ 2304.75

   3 mos

   (b) Secretarial Assistance (Mrs. Elaine Wigham)
   1.25 months @ 943/mo (US) — 1178.75

   (c) Professional
   H. Steppuhn - review of literature, working trips including final seminar, administrative and major report writing responsibility
   300 hrs @ $15/hr — 4500.00

   D.M. Gray - working trips, review of initial analysis and conclusions, preparation of report and final review
   100 hrs @ $20/hr — 2000.00

   11,264.95

2. Travel - to research and operational units.
   3 or 4 trips to Wyoming, Colorado, North Dakota Montana and possibly Alberta
   Airfare and/or auto(equivalent) — 1180
   Sustenance 14 days @ ~~$50~~ 35 — ~~700~~ 490

   - to seminar in Denver
   Airfare and taxi (Saskatoon-Denver) — ~~230~~ 300
   Sustenance 3 days @ $50 — ~~150~~ ~~380~~ 480

   ~~2,260.00~~ 1670

3. Supplies

telephone	300
copying, printing, drafting	300
library search & material requests	400
incidentals	200

   1,200.00

4. Other
   - computerized library search and computer formating of data — 300

5. Misc.

TOTAL $ 15,024.95 US

CONTRACT 15,000.00

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Off-campus (480)(.15) = 72.00

(~~1880~~ 1670)(.02) = 33.40

1366.45

1366.45 + = 15,000

9%

THE POTENTIAL FOR SNOW MANAGEMENT IN SURFACE

COAL-MINE RECLAMATION

The need for snow management ~~in mined-land reclamation~~ is greatest where water is in short supply. It happens that large deposits of coal, whose removal appears feasible by surface mining

Fig. 1 ~~(Figure 1)~~, are located in a large mid-continental, water-deficient region (Toy, 1979). A measure of potential water-deficit for a region can be obtained by comparing the mean annual values of precipitation and Class A pan evaporation measurements. If the latter exceeds the former by two-fold or more as shown for the mid-con-

Fig. 2 tinental region in Figure 2, aridity is indicated. Water deficits over the region become especially large in the summer. During the winter, precipitation in the form of snow often exceeds evaporation. Also, air temperatures are low enough to result in the formation of snowcovers which release considerable water upon melting.

Although mean annual snowfall is not uniformly distributed

Fig. 3 over the region (Figure 3), waters derived from the snow form a sizeable resource. The quantity of water from just one snowfall distributed to a depth of six inches (15 cm) over the northern Great Plains (1,865,000 km^2) contains 106.8×10^9 m^3 of water (at snow density of 0.375 g/cm^3), an amount equal to half the mean annual volume (1958-73 19) flowing from the North American Great Lakes into the St. Lawrence

where is this? River (Water Survey of Canada, 1974). A resource in the form of snow is indeed available for management to use where needed including over mined-lands under reclamation. Snowfall statistics recorded during

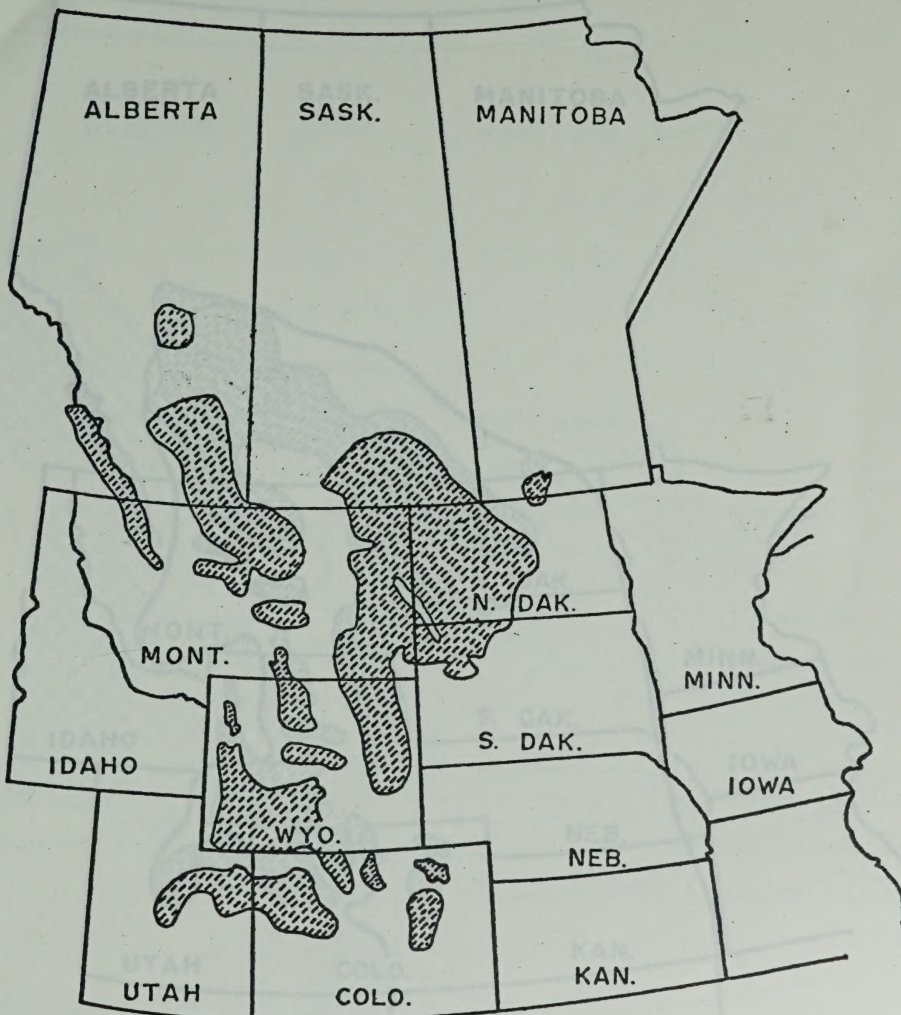

Figure 1. Location of mid-continental coal resources of all types (Bur. of Land Management, 1978).

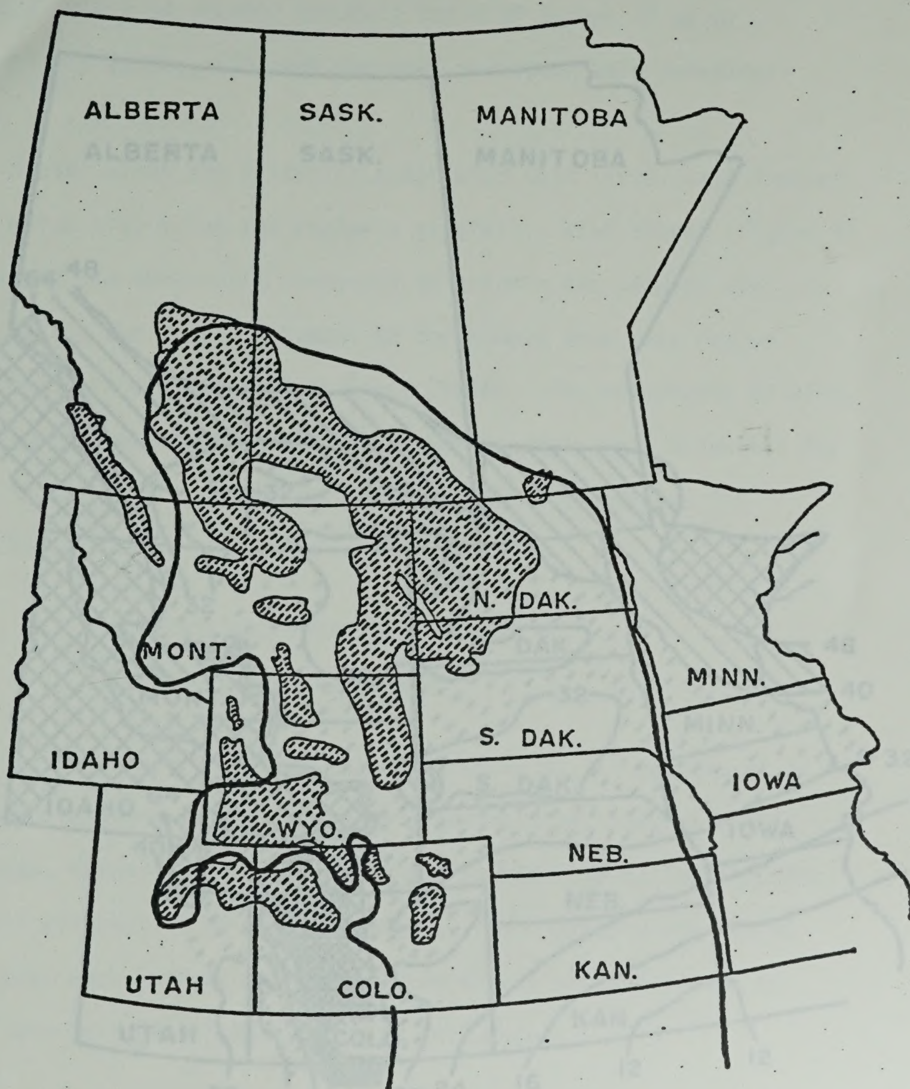

Figure 2. Location of mid-continental coal resources and the mid-continental region of large annual water deficits (as bounded by the heavy line) where the mean annual evaporation from Class A Pans exceeds the mean annual precipitation by two fold or more.

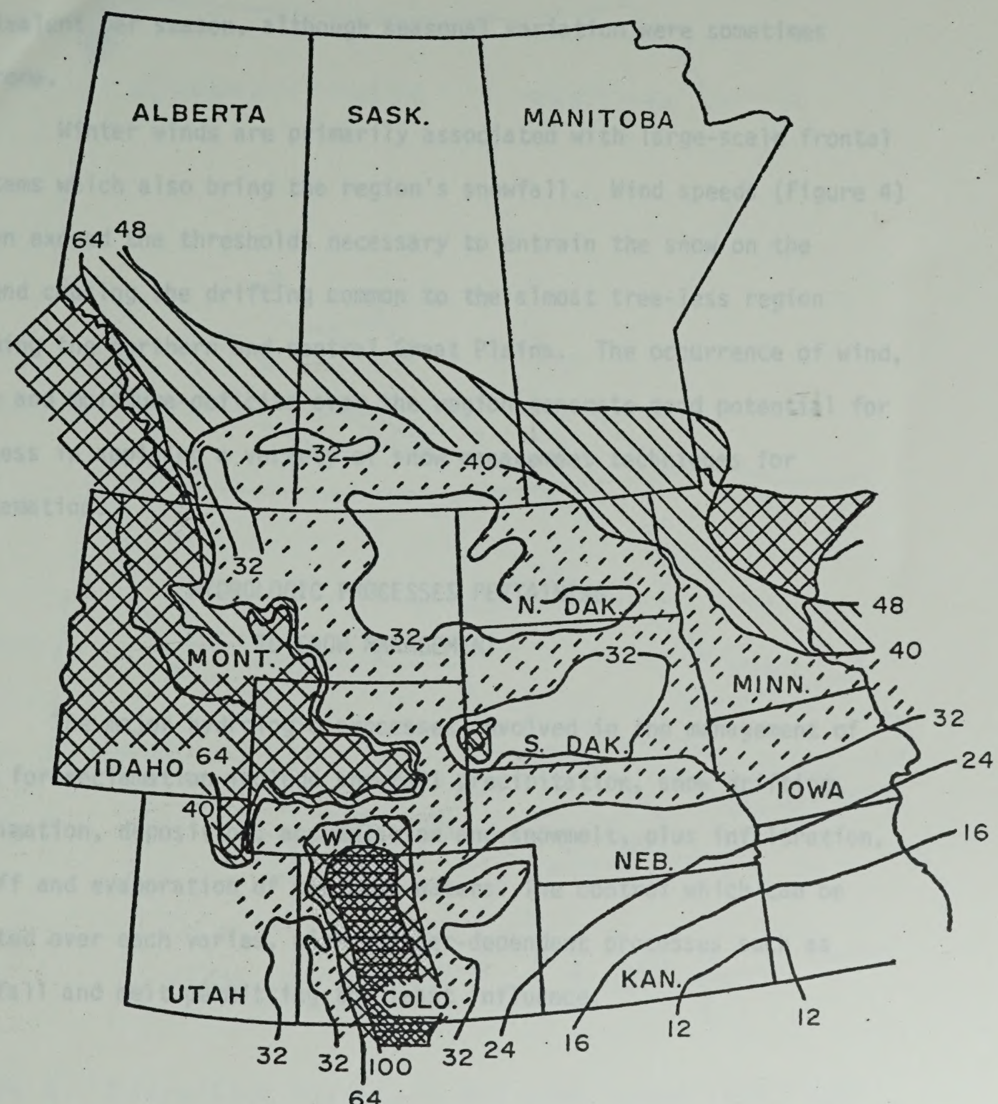

Figure 3. Mean annual snowfall over the mid-continental region in inches of snow depth assuming no melt or sublimation (Monthly Weather Records, Weather Service, U.S. National Ocean. and Atmo. Admin., Washington, D.C. and Canadian Atmo. Environ. Service, Ottawa).

19 years at Akron, Colorado, showed an average of 12 snowfall events and 13.6 days of snowfall per season (Greb, 1975). These storms produced 32.7 inches of average snowfall and 3.89 inches of water equivalent per season, although seasonal variation were sometimes extreme.

Winter winds are primarily associated with large-scale frontal systems which also bring the region's snowfall. Wind speeds (Figure 4) often exceed the thresholds necessary to entrain the snow on the ground causing the drifting common to the almost tree-less region forming the northern and central Great Plains. The occurrence of wind, snow and moisture-deficits over the region generate good potential for success in applying a variety of snow management techniques for reclamation.

HYDROLOGIC PROCESSES PERTAINING TO SNOW MANAGEMENT

The major hydrologic processes involved in the management of snow for reclamation include snowfall precipitation, snow drifting, sublimation, deposition, accumulation and snowmelt, plus infiltration, runoff and evaporation of the melt waters. The control which can be exerted over each varies, with weather-dependent processes such as snowfall and melt permitting the least influence.

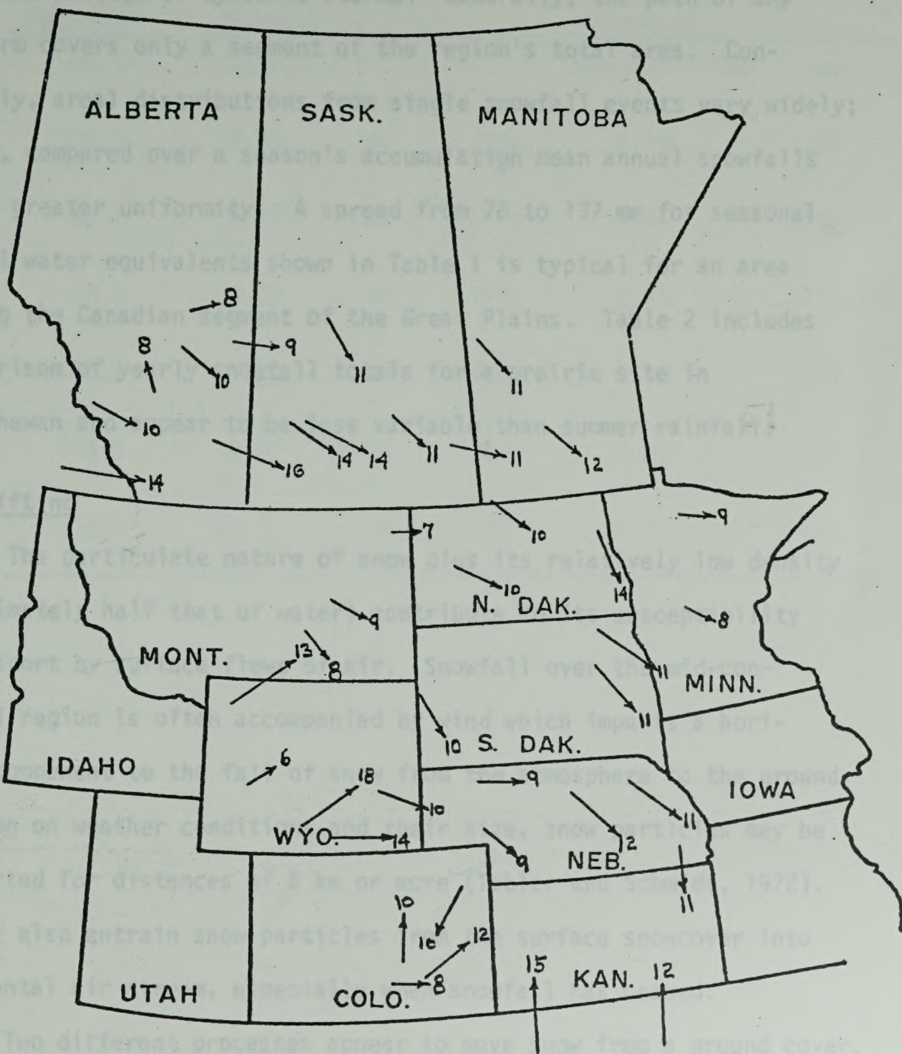

Figure 4. Prevailing direction and mean speed (mph) for January wind (Grant, L.O. and J. Ramirez, 1975).

Snowfall Precipitation

The bulk of the snow over the mid-continental region falls during the passage of cyclonic storms. Generally, the path of any one storm covers only a segment of the region's total area. Consequently, areal distributions from single snowfall events vary widely; however, compared over a season's accumulation mean annual snowfalls exhibit greater uniformity. A spread from 78 to 137 mm for seasonal Table 1 snowfall water equivalents shown in Table 1 is typical for an area Table 2 equaling the Canadian segment of the Great Plains. Table 2 includes a comparison of yearly snowfall totals for a prairie site in Saskatchewan and appear to be less variable than summer rainfall.

Snow Drifting

The particulate nature of snow plus its relatively low density (approximately half that of water) contribute to its susceptibility to transport by surface flows of air. Snowfall over the mid-continental region is often accompanied by wind which imparts a horizontal component to the fall of snow from the atmosphere to the ground. Depending on weather conditions and their size, snow particles may be transported for distances of 5 km or more (Tabler and Schmidt, 1972). Wind may also entrain snow particles from the surface snowcover into a horizontal air stream, especially when snowfall has ceased.

Two different processes appear to move snow from a ground cover. In weak winds the snow particles roll, skip or glide along the surface and only occasionally concentrate into streams deflected upward by surface irregularities (Radok, 1977). Owen (1964) described this

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Table 1. Accumulated snowfalls, hourly averaged 10 m wind speeds, numbers of storms with wind speeds above threshold for drifting (7 m / s), total storm hours, estimated snow transport and potential sublimation at six Canadian climatological stations during Winter 1974-75

Station	Accumulated snowfall water equivalent	Average hourly wind speed	No. of storms	Storm hours	Estimate of maximum possible snow transport	Potential sublimation
	mm	m/s			tonnes/m width	mm
Winnipeg Manitoba	129.3	9.08	41	900	9.18	109
Regina Saskatchewan	82.0	9.35	48	1115	13.01	185
Saskatoon Saskatchewan	78.0	8.80	40	686	5.88	122
Bad Lake Saskatchewan	101.2	9.38	33	763	8.95	162
Edmonton Alberta	108.0	8.73	27	329	2.62	64
Lethbridge Alberta	136.6	10.5	39	1087	21.74	765

Table 2. Precipitation Summary, 1968-78, Bad Lake Climatological Station near Bickleigh, Saskatchewan, operated by Atmospheric Environment Service of Canada and the Division of Hydrology, University of Sasaktchewan

Year	Rainfall 16 August through 15 May	Snowfall Water Equivalent October-April	Rainfall 16 May through 15 August 1/	Total Precipitation 16 August-15 August	Snow/Total Ratio
	mm	mm	mm	mm	%
1967-68	75	75	105	255	29
1968-69	139	108	130	377	29
1969-70	98	148	195	441	33
1970-71	33	108	151	292	37
1971-72	31	91	132	254	36
1972-73	48	83	72	203	40
1973-74	66	167	260	494	34
1974-75	59	101	145	305	33
1975-76	29	84	194	307	27
1976-77	98	39	146	283	14
1977-78	62	104	108	274	38
Mean 1968-78	67.1	100.6	148.9	316.7	32
Standard Deviation	±33.9	±34.5	±51.7	±86.5	±5

1/ Summer growing season.

saltation mode of transport mathematically, while Kobayashi (1972) recorded this movement at velocities of around 5-6 m/s at the one-cm level. When the wind velocity increases above a threshold which depends on the surface, temperature, etc., the snow in transport begins to go into a state of suspension by turbulent diffusion. Threshold velocities generally approach 8 to 16 m/s before this motion occurs.

Two main theories of drifting processes developed independently. They differ mainly in the proportion of the total transport taking place at different levels, the processes that dominate and the extent of the vertical scales. The Australian theory, described by Budd, Dingle and Radok (1966), Budd (1966) and others, views most transport occurring primarily because of large eddies in a free air stream which may extend tens of meters above the surface. They hold that the concentration, n_z, at a height z of a mass of uniform snow particles with fall velocity w is governed by the relation

$$n_z w = k u^* z \frac{\partial n_z}{\partial z},$$

where k and $u^* = (\tau/\rho)^{0.5}$ are the von Karman constant and shear velocity in the logarithmic wind profile, $V_z = (u^*/k) \ln (z/z_0)$, valid for a surface roughness length z_0 and stress τ (Radok, 1968).

The Siberian theory for snow drifting has been presented by Dyunin (1954a, 1959, 1967) and supported by Komarov (1954). The theory emphasizes snow drift as a near-surface phenomenon due to small eddies in the lowest 10 cm producing mainly saltation. The

theory also suggests that a threshold pressure deficit or velocity must be exceeded to break the bonds between the surface snow grains. Working equations usually express total transport Q as a function of wind speed V_z at height z (Dyunin, 1954b), such as

$$Q = 0.34 \, (V_{0.2} - 3)^3$$

with Q given in g/(ms), V in m, and z in m (Dyunin, 1974).

The distance over which a flow of surface wind can entrain particles of snow represents a contributing distance within a field of fetch for the wind. Such fetch is often taken as that distance extending upwind from a major snow depositional area, such as a row of trees or a deep gully to another such accumulation area. Manipulation of the surface roughness within the zone of fetch provides the major opportunity available to exert some control or management over the drift of snow; the smoother the surface, the greater the snow entrainment. Although the fetch may be large, not all the snow in the fetch field will travel the entire distance; every particle of wind-transported snow, under most weather conditions, looses mass in a wind stream even to the point of complete sublimation before reaching the depositional area.

<u>Sublimation of Snow in Transport</u>

The mass sublimation of a snow particle suspended in a turbulent air stream exceeds that occurring when the particle is at rest in a snowcover. The process results from a vapor pressure difference between the particle and surrounding layer of air. The rate of

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sublimation depends on the rate at which air is exchanged in the ambient layer ventilated with respect to water vapor. Energy, measured by heat, is transferred to or from the particle surface by conduction, convection, radiation, and mass movement (water vapor) through diffusion and convection.

Dyunin (1959) was one of the first scientists to include a sublimation component in his general snow flux model. Tabler and Johnson (1971) listed the recovery of water normally lost in transit by sublimation as one of the chief benefits from snow fences placed in open watersheds within the mid-continental region. In (1972) Schmidt introduced a mathematical model to estimate sublimation rates for blowing snow based on the laboratory work of Thorpe and Mason (1966). The model uses on-site air temperature, relative humidity, wind speed, and total solar radiation to calculate maximum transport distances for complete sublimation of various size snow particles. For a site in southeastern Wyoming with a mean wind of 11.8 m/s, relative humidity of 72.1%, air temperature of -7.7 ^{o}C, and a solar radiation of 16.9 cal/cm^2 hr, Tabler and Schmidt (1972) estimated sublimation transport distances of 457, 899 and 1421 m for particle diameters of 0.1, 0.15 and 0.2 mm, respectively. The concept of a transport distance for blowing snow based on the average distance an average-size particle must travel before completely sublimating was introduced by Tabler for determining storage capacity in snow-fence systems in (1971) and for estimating mass losses in wind-blown snow in (1973).

Schmidt's (1972) model assumes that the movement of any snow particle in an air stream does not lag or "slip" in relation to wind

speed. In a detailed investigation, Lee (1975) showed that inaccuracies in estimating sublimation rates based on the "no-slip" assumption are small. For example, where Schmidt's analysis concludes that instantaneous sublimation rate (dm/dt) of a particle of ice at time t is approximately proportional to the 3/2 power of its diameter (x) at time t, Lee's model under Wyoming conditions would give the approximate relationship.

$$dm/dt = k\,x^{1.4}$$

over the diameter range 0 to 0.5 mm and a negative constant k.

The method for estimating sublimation losses from wind-blown snow proposed by Tabler in (1973) assumed a linear relationship with travel distance. The transport distance (R_m) was defined as the average distance a snow particle must travel before completely sublimating (Figure 5). The contributing distance or fetch (R_c) upwind of a natural barrier or snow fence might be less than R_m but could not exceed it. Under steady-state and uniform conditions, the mean sublimation loss (Q_L) over the distance R_c covered with P_r snow water equivalent was estimated by

$$Q_L = P_r\,(R_c^2/2R_m).$$

In a later model, Tabler (1975) suggested an exponential function which defined the transport distance (R_μ) as the distance traveled by the snow particle with the mean diameter μ:

$$Q_L = P_r R_c - \frac{P_r R_\mu}{2}\,[1-(0.14)^{R_c/R_\mu}].$$

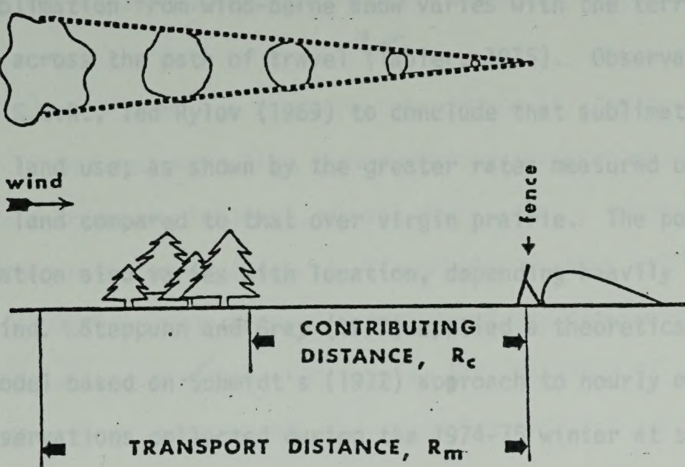

Figure 5. Diagram of the transport distance concept used to estimate sublimation loss from wind-transported snow. The <u>transport distance</u>, R_m, is defined as the average distance over which a snow particle (shown between the convergent dotted lines) must travel before it completely sublimates. The <u>contributing distance</u>, R_c, is defined as that distance upwind which contributes blowing snow to a site, and may be equal to, or less than, R_m. (Taken from Tabler, R.D. 1973. Evaporation Losses of Windblown Snow, and the Potential for Recovery. 41st Meeting of the Western Snow Conference, Proceedings)

Although the equation is empirically based on Wyoming conditions, the author suggests that it should be valid to estimate seasonal sublimation quantities in a wide range of climates and locations.

Sublimation from wind-borne snow varies with the terrain and vegetation across the path of travel (Tabler, 1975). Observations in Kazakhstan S.S.R., led Rylov (1969) to conclude that sublimation is related to land use; as shown by the greater rates measured over cultivated land compared to that over virgin prairie. The potential for sublimation also varies with location, depending heavily on total seasonal wind. Steppuhn and Gray (1977) applied a theoretical sublimation model based on Schmidt's (1972) approach to hourly meteorological observations collected during the 1974-75 winter at six stations on the Canadian Prairies. The average winter snowfall was 105.8 mm; estimates of the average maximum seasonal amounts of snow that could have been transported by wind and sublimated were 10.2 tonnes per meter width and 235, respectively. The values estimated at individual stations

Table 1

differed considerably (Table 1). Potential sublimation estimated at four of the six stations exceeded the measured snowfall; however, the actual amounts sublimated were less because potential values assume that an unlimited supply of snow moves in a saturated air stream.

Snow Deposition and Accumulation

The forces which keep a particle of snow air-borne result from the wind's turbulent character. Within any horizontal wind stream, turbulence causes individual elements of air to move in all directions, even upward against gravity. This upward motion, plus any vertical

momentum acquired by the particles, imparts the transient force which bouys the snow in a wind stream. Any increase in net horizontal speed strengthens the upward vector and multiplies the capacity for snow transport. Conversely, a decrease in speed reduces capacity and allows deposition.

Speed reductions are a natural phenomenon of wind transport and result in the many wave-like, snow-deposited surfaces which have been observed (ripples, sastrugi, waves, dunes, etc.). Wave-lengths are about the same size as the scale of turbulence. Work by Kobayashi, Shiraishi, and Ishida (1979) indicate that wind turbulence and snow-wave formation interact with each other. Certainly, the existence of wind-break barriers, natural or constructed, in a snow-ladened wind stream will cause deposition in response to wind speed reduction (Woodruff, 1954; Greb, 1975a; Siddoway, 1968).

Evidence that wind controls snow deposition in prairie environments has been provided by Kuz'min (1960), Steppuhn and Dyck (1974). These studies, concerned with measurement of areal snowcover depth and water equivalent, recognized the influence of landscape features (e.g., terrain, vegetative cover and land use) on the distribution patterns of snow in windy regions. The snowcover water equivalents

Table 3

and accumulation ratios (of the areal average) given in Table 3 attest to the non-uniformity of a mid-continental snowcover. Martinelli (1965a) and Van Haveren (1974) reported on the dominating effect of terrain features on snow accumulation, while Hutchison (1965) and Sturges (1975) observed large catches of snow behind shrubs protruding above a grass cover. Sturges (1977) even detected a small ($\leq$ 5 cm) but

Table 3. Relative Snowcover Accumulation Ratios According To Landscape Classes Based on March 1974 and March 1975 Comprehensive Snow Surveys, Creighton Watershed, Southwestern Saskatchewan

SNOWCOVER ACCUMULATION RATIOS

LANDSCAPES	WE* mm (March 1974)	WE mm (March 1975)
Hilltops		
fallow	62	13
stubble	81	46
pasture	53	24
Plains		
fallow	103	62
stubble	115	76
Rolling Plains		
fallow	128	62
stubble	120	60
pasture	136	72
Gradual Slopes		
fallow	124	62
stubble	109	65
pasture	153	72
Gradual Drainages		
fallow	279	97
stubble	226	104
pasture	242	104
brush	284	162
Steep Slopes		
pasture	279	
brush	355	308 (4.2→)
Farm Yards	339	91
Entire Watershed weighted by area	133	73

* WE = Actual Snow Water Equivalent

significant reduction in snow depth on sagebrush plots sprayed with 2,4-D compared to untreated plots.

The placement of various barriers across a snow-laden wind offers the best opportunity for controlling the accumulation and distribution of snowcovers, i.e., for effecting snow management. Based on objective, three classes of barriers were recognized by Mellor (1965):

(1) Collectors, arranged perpendicular to the direction of the main snow-bearing wind so that snow will drop from the passing air stream;

(2) Blowers, constructed with such a design that they accelerate wind flow locally and thus keep the surface scoured and snow-free;

(3) Deflectors, aligned at angles to the wind, so that they direct snow and wind where desired.

Although Kind (1976) isolated an extensive set of conditions for the simulation of wind-induced snow drifting, Theakston (1961), Gerdel and Strom (1961), Wuebben (1978), and many others have modeled the phenomenon under laboratory conditions. Despite the difficulty in similitude of sand and water for snow and air, the analogy appears useful on a practical basis. Simulation of the atmospheric boundary layer is of primary importance. While accurate modeling of the boundary layer thickness may not be possible, the model structure should be comparatively small. Recently, Tabler (1979) demonstrated that drifts formed by snow fences appear to be naturally scaled at a 1:30 scale. Natural scaling of drifts suggests

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snow erosion and deposition can be studied with reduced-scale models on smooth surfaces outdoors.

Snowmelt

The processes which govern the melting of snow involve various transfers of energy between the medium and its environment. As defined by the U.S. Corps of Engineers (1956), these transfer processes include:

(1) Conduction of energy from the ground, H_g;

(2) Absorbed solar radiation, R_s;

(3) Net terrestrial and atmospheric radiation, R_n;

(4) Condensation or vaporization from the air, R_e;

(5) Convectional energy transfer by wind, R_h;

(6) Energy content of rain water, H_r.

If M = water equivalent of the melted snow (inch),

E = ratio of energy required to melt a unit weight of snow to that of ice at $0^{o}C$ (varies with liquid water content of snow), and

203 = a constant for the energy (cal/cm^2) required to convert one inch of melt water from snow at $0^{o}C$, then

$$M = (H_g + R_s + R_n + R_e + R_h + H_r)/(203\ E).$$

Manipulation of the snow to effect specific management aims unquestionably alters the natural sequence of snowmelt. Not only is surface reflectivity modified changing the rate of melt, but additions to snowcover mass increase its internal energy capacity and phase change requirements. Matthews (1940) observed that melt accelerated

in plowed snowcovers containing an enrichment of soil particles resulting from tractor operations used to create wind barriers. Similarly, snow caught in a taller crop stubble will melt faster than snow trapped in a shorter stubble (Willis et al., 1969). Apparently, taller plant stalks can cause a greater absorption of radiant energy. Unfortunately, specific influences of snow management on melt has not been studied in detail.

Disposition of Snowmelt Waters

Water melted from snow may move toward three possible fates: runoff toward surface water bodies far or near; evaporation into the atmosphere; and, infiltration into subsurface media. The snow covering a 10.5 Km^2 prairie watershed in western Saskatchewan was surveyed comprehensively at the time of peak accumulation in March 1974 (Steppuhn and Erickson, 1978). The survey taken just prior to the spring melt period indicated a non-uniform snowcover distributed fairly consistently according to topography and land use (Table 3). Weighted by the total area in each landscape type, the areal mean water equivalent for the snowcover had it been uniformly distributed was 133 mm. Runoff waters from the melting of this snow were measured at a stream gaging station or as a surface volume stored in two farm ponds and represented 32% of the snow water available for melt (133 mm). Tracer studies indicated that another 18% evaporated from water and soil surfaces. Consequently, about half of the melt water infiltrated into the subsurface media.

In central North Dakota during another year, Willis et al. (1961) measured soil surface infiltrations equalling only 12% of the snowcover water, while in eastern North Dakota Bauder et al. (1975) recorded less than 10%. These values follow the expected in that soil water contents tend

to increase eastward from Saskatchewan to eastern North Dakota. In studying water entry to frozen prairie soils Gillies (1968) found that the infiltration rate varied as an inverse exponential function of the initial soil water content of the surface layer (0 to 5 cm depth). Larkin (1962) indicated that if a soil is frozen at a water content greater than field capacity, its infiltration rate will be very low. Also, soil that is wet in the fall freezes slower and not as deep as soil that is dry in the fall (Willis and Carlson, 1961). By way of speculation, Gray et al. (1970) presented several possible graphical functions (Figure 6) describing the time variation in the infiltration rate into frozen soil based on water content and temperature.

Fig. 6

The objectives of snow management within the mid-continental region dictate the desired fate of snowmelt waters. Some objectives would aim to retard infiltration, e.g. snow water harvesting to augment surface supplies. Other objectives, especially those involving soil water enhancement, require maximum infiltration. Generally, however, the minimization of evaporation is desireable throughout the region for all objectives.

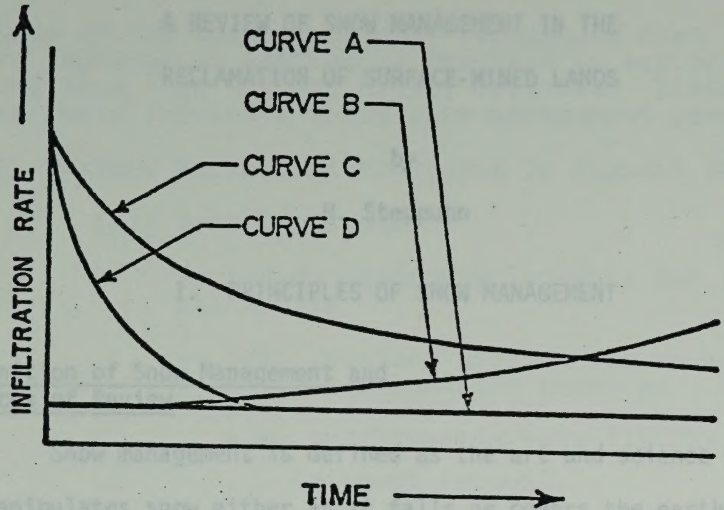


Figure 6. Conceptual diagram of time variation in infiltration rate of frozen soils (Gray et. al., 1970).

Curve A:
Infiltration characteristics which prevail when the soil is frozen when saturated, or when an impervious ice layer develops on the surface during the melting period.

Curve B:
Conditions which may exist when a soil is frozen at a high water content. Some of the melt water is able to penetrate the soil and thus transfer heat to melt the ice. As the soil warms and the ice melts, the infiltration capacity increases.

Curve C:
Infiltration rate when the soil is frozen at a low water content and the soil temperature is near or above freezing. The ice thaws rapidly with the downward movement of water and infiltration proceeds as under unfrozen conditions.

Curve D:
This curve represents the condition in which the soil is frozen at a low water content but the soil temperature at the time of snowmelt is below freezing. Water entering the soil is frozen and movement is inhibited.

Reference: Gray, Donald M., Donald I. Norum and John M. Wigham, 1970. Infiltration and the physics of flow of water through porous media. Section V. Handbook on the Principles of Hydrology, Secretariat Canadian National Committee for the International Hydrologic Decade, NRC, Ottawa, Canada, p. 5.15.

A REVIEW OF SNOW MANAGEMENT IN THE RECLAMATION OF SURFACE-MINED LANDS

by

H. Steppuhn

I. PRINCIPLES OF SNOW MANAGEMENT

Definition of Snow Management and Focus of Review

Snow management is defined as the art and science which utilizes or manipulates snow either as it falls or covers the earth with the object of realizing specific benefits. Applied to surface-mine reclamation, snow management can be employed to augment soil water, to fill water storage facilities, to insulate overwintering plants, to remove undesired snow from specific sites, and to reduce soil erosion by wind. Many reclamation goals parallel those in agriculture, namely, to grow healthy plants over large areas (often in harsh environments), to stabilize the surface soil, and to minimize rapid, flood-causing surface runoff. The hydrologic processes involved to effect snow management include precipitation of the snow in the atmosphere, transport and deposition of wind-borne snow, sublimation from snow particles especially while in motion, and disposition of the water upon melting. Implementation of snow management for the reclamation of lands used in surface mining depends on its technical feasibility, economic viability and suitability with respect to need and location.

II SNOW MANAGEMENT APPLICABLE TO RECLAMATION OF SURFACE-MINED LANDS

Many of the snow management techniques most applicable to reclamation evolved in response to agricultural needs, and thus, are agriculturally oriented. Listed according to their objective these snow management practices are:

II-I Snow Management Practices To Augment Soil Water

(a) Soil Requirements

Spread and maintain top-soil and subsoil over all spoils

-- Soil provides storage for snowmelt water
-- Water infiltration promoted

e.g. infiltration rate (in./hr.)	1st hr	2nd hr
without topsoil	2.88	0.42
with topsoil	6.47	1.93

-- Soil wedge over spoils showed increasing benefits as thickness of soil increased up to 28 in. for either 8 or 24 in. of top soil.

(b) Maintenance of crop residues overwinter (crop stubble management)

-- Trap snow with crop stubble

Table 2

e.g. (1) wheat stubble at Swift Current, Saskatchewan (Table 2)
(2) sunflower stubble traps more than wheat stubble (in Sask. 32 cm for sunflower and 15 cm for wheat)

TABLE 2 —MOISTURE CONSERVED IN STUBBLE AND FALLOW FIELDS OVER-WINTER, SOUTHWESTERN SASKATCHEWAN

Season	Stubble				Fallow			
	Fall moisture	Rainfall	Snowfall	Conserved	Fall moisture	Rainfall	Snowfall	Conserved
	in.	in.	in.	in.	in.	in.	in.	in.
1936–37	0.19	0	1.77	1.42	0.42	0	1.77	0.78
1937–38	0.68	2.06	5.28	3.46	1.41	0.25	5.28	0.70
1938–39	1.06	1.04	2.85	1.80	5.04	1.04	2.85	—0.66
1939–40	—0.10	1.59	3.01	3.08	4.06	0.93	3.01	1.15
1940–41	—0.51	3.07	2.12	1.64	4.55	0.40	2.12	—0.24
1941–42	0.86	5.80	2.58	3.02	1.44	0.89	2.58	0.14
1943–44	2.33	0.43	2.22	0.93	4.71	0.43	2.22	0.06
1944–45	1.02	2.74	2.94	3.06	4.56	1.34	2.94	0.04
1945–46	2.40	0.87	2.66	0.27	4.49	0.87	2.66	—0.12
1946–47	2.33	0.52	3.88	0.85	3.49	0.52	3.88	—0.09
1947–48	0.29	2.30	4.10	1.00	3.69	2.30	4.10	0.86
1948–49	—0.06	0.29	3.00	1.51	2.82	0.29	3.00	—0.06
1949–50	—0.41	3.95	4.30	2.77	1.15	3.24	4.30	1.64
1950–51	0.11	1.06	6.61	4.41	5.03	0.59	6.61	—0.10
1951–52	4.57	1.44	5.43	0.85	6.16	1.44	5.43	—0.25
1952–53	2.43	1.78	4.69	2.83	3.23	1.78	4.69	1.11
1953–54	1.06	1.23	2.77	1.11	5.93	1.52	2.77	0.28
1954–55	5.68	4.35	3.22	2.55	6.84	5.03	3.22	2.20
1955–56	1.89	0.57	4.95	1.31	5.73	0.99	4.95	0.92
1956–57	0.24	1.27	4.90	2.40	5.07	1.27	4.90	0.19
Mean	1.30 (33mm)	1.82 (46mm)	3.66 (93mm)	2.01 (51mm)	3.99 (101mm)	1.26 (32mm)	3.66 (93mm)	0.43 (11mm)
				(36.7%)				(8.8%)

Taken from:

Staple, W.J., J.J. Lehane and A. Wenhardt. 1960. Conservation of soil moisture from fall and winter precipitation. Canadian Jour. of Soil Science, 40: 80-88.

-- taller stubble most effective
(At Williston, North Dakota)

Wheat Residue Height		Snow Water Equivalent	Available Soil Water
winter	0 (cm.)	2.0 (cm.)	1.4 (cm/120cm)
1976-77	18	3.6	2.4
	36	7.4	4.7
winter	0	2.3	4.3
1977-78	15	4.3	5.7
	30	6.8	6.6

-- grasses grown in contour rows

-- Snow from taller stubble may also increase runoff
At Mandan, North Dakota

wheat stubble height (in.)	0	10	20
runoff (% of snow cover)	57	67	69

-- Fertilization produces taller plants, but reduces water use per unit production e.g. spring wheat in Saskatchewan

	stubble	fallow
	(mg grain/g H_2O)	
No fertilizer	0.59	0.66
Fertilizer	0.75	0.82

-- Alternate height double swathing

Cereal crops are often cut and windrowed prior to combining. Cutting swaths at alternate heights of 9 and 6 inches increased snow water catch by 0.6 in. over a uniform height stubble of 6 in.

-- Straight combining leaves a taller stubble

Table 3 -- Fall cultivation generally reduces field snowcover and soil water reserves (Table 3)

-- Grazing intensity of pastures and range; less grazing leaves taller plants:
(see handout material, Ref. No. 3)

(c) Non-Vegetative Barriers

(1) Field Fences

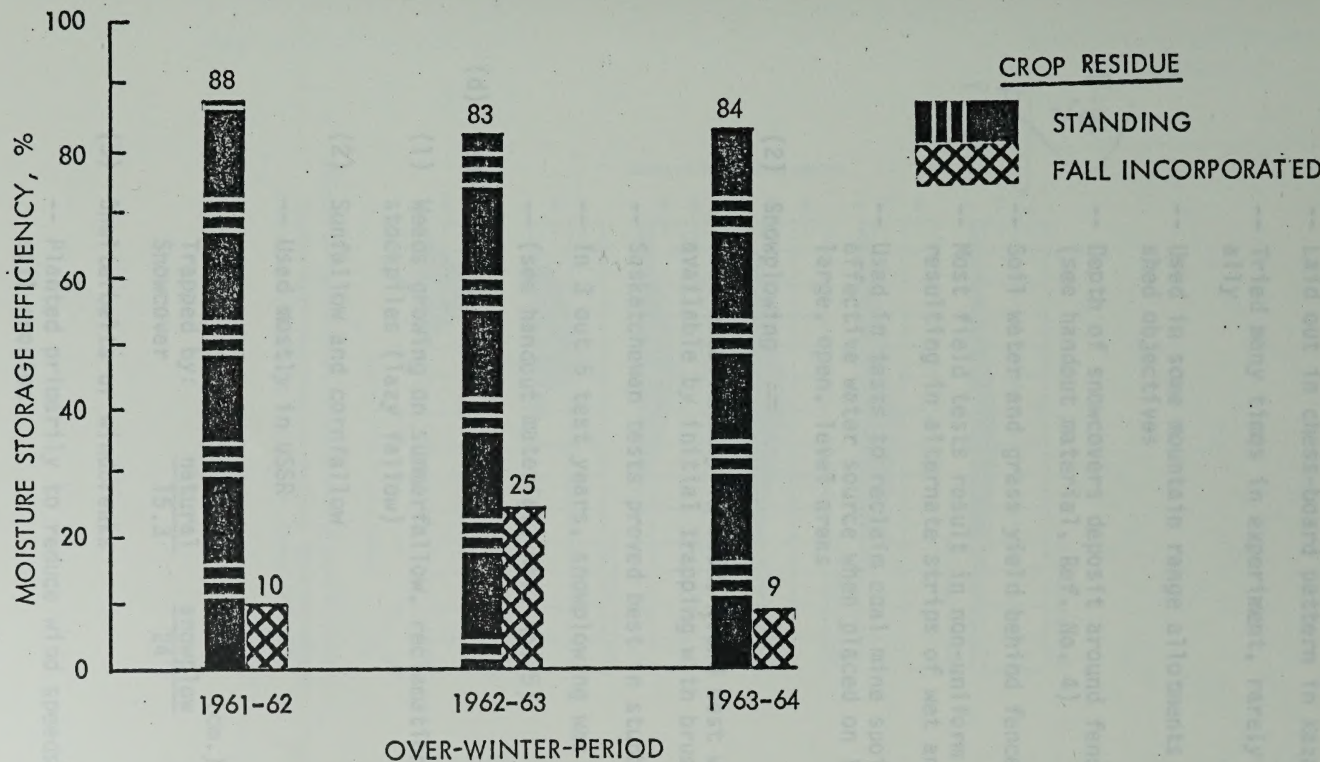
-- Will trap snow if placed downwind of a snowfetch

-- Brush, wood-on-wire, all wood, plastic net

TABLE 3.

EFFECT OF SURFACE RESIDUE ON THE STORAGE OF SOIL WATER FROM SNOW (November 15 through March 31), NORTH PLATTE, NEBRASKA (from Smika and Whitfield, 1966).

Over-winter period	Residue	Available soil water to 1.83 m depth, cm		Precip-itation cm	Storage Efficiency %
		Nov 15	March 31		
1961-62	Standing	9.4	14.5	5.8	88.2
	Fall incorporated	9.9	10.5		10.0
1962-63	Standing	13.9	18.8	5.8	83.3
	Fall incorporated	15.3	16.8		25.3
1963-64	Standing	11.2	16.8	6.7	83.6
	Fall incorporated	9.9	10.5		8.8
1964-65	Standing	14.2	19.3	3.6	140.6
	Fall incorporated	14.2	10.4		-105.6



EFFECT OF SURFACE RESIDUE ON THE MOISTURE STORAGE FROM SNOW,
NORTH PLATTE, NEBRASKA (NOVEMBER 15 through MARCH 31)
(Smika and Whitfield, 1966)

Companion Graph to Table 3.

-- Laid out in chess-board pattern in Kazakhstan S.S.R.

-- Tried many times in experiment, rarely used operationally

-- Used in some mountain range allotments and for watershed objectives

Fig. 7 -- Depth of snowcovers deposit around fences (Figure 7) (see handout material, Ref. No. 4)

Fig 8 & 9 -- Soil water and grass yield behind fences (Figure 8 & 9)

-- Most field tests result in non-uniform snow distribution, resulting in alternate strips of wet and dry soils

-- Used in tests to reclaim coal mine spoils in Wyoming; effective water source when placed on leeward side of large, open, level areas

(2) Snowplowing

-- Used occasionally in USSR; found best when snow was available by initial trapping with brush fences

-- Saskatchewan tests proved best in stubble fields

-- In 3 out 5 test years, snowplowing was not successful

-- (see handout material, Ref. No. 5)

(d) Vegetative Barriers

(1) Weeds growing on summerfallow, reclamation site, and soil stockpiles (lazy fallow)

(2) Sunfallow and cornfallow

-- Used mostly in USSR

e.g.

		(cm.)	
Trapped by:	natural	snowplow	sunflower fence
Snowcover	15.3	24	42

(3) Shelterbelts or windbreaks

-- Planted primarily to reduce wind speeds and retard soil erosion

-- Also traps snow, especially around farm yards; snow from farm yard shelterbelts provides soft water for stock and domestic use

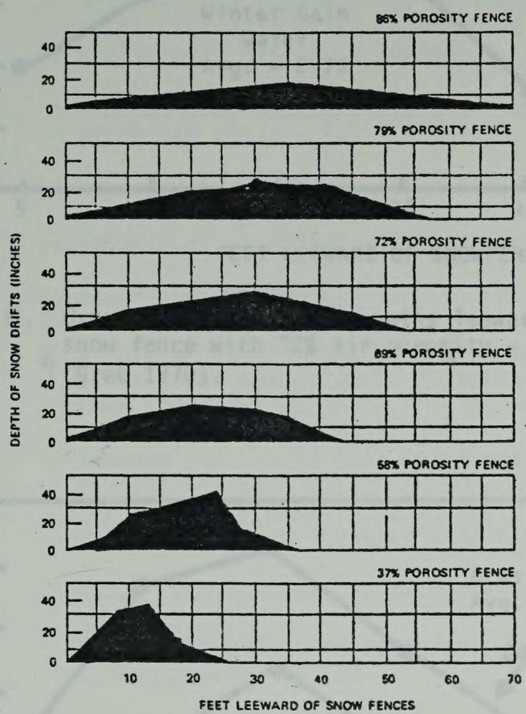


FIGURE 7.—Influence of snowfence porosity on drift deposits. Typical snow accumulation resulting from 30-mile-per-hour wind with 6 inches of dry snow, Akron, Colo. (22).

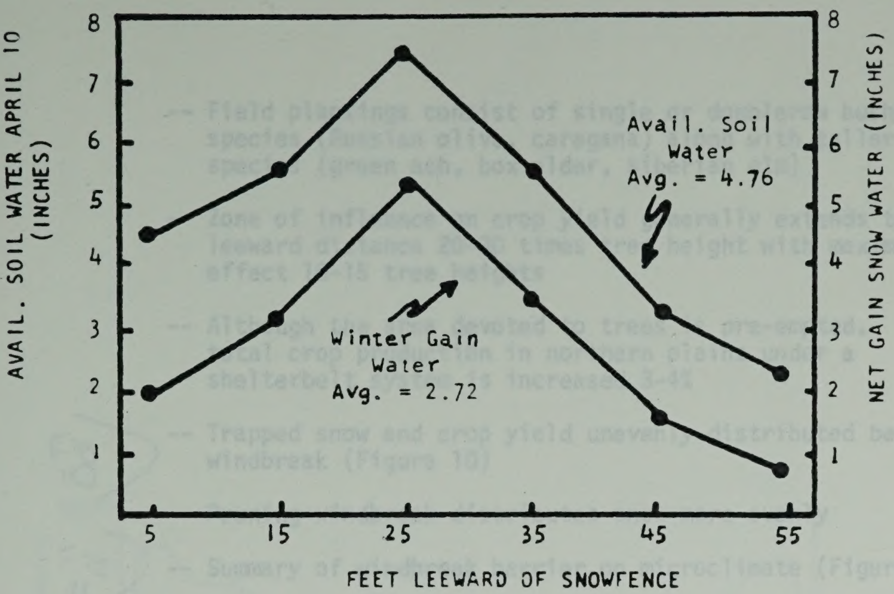


Fig. 8. Over-winter soil water gains leeward of a wood-slat snow fence with 72% air porosity - Akron, Colorado ? (Greb 1970).

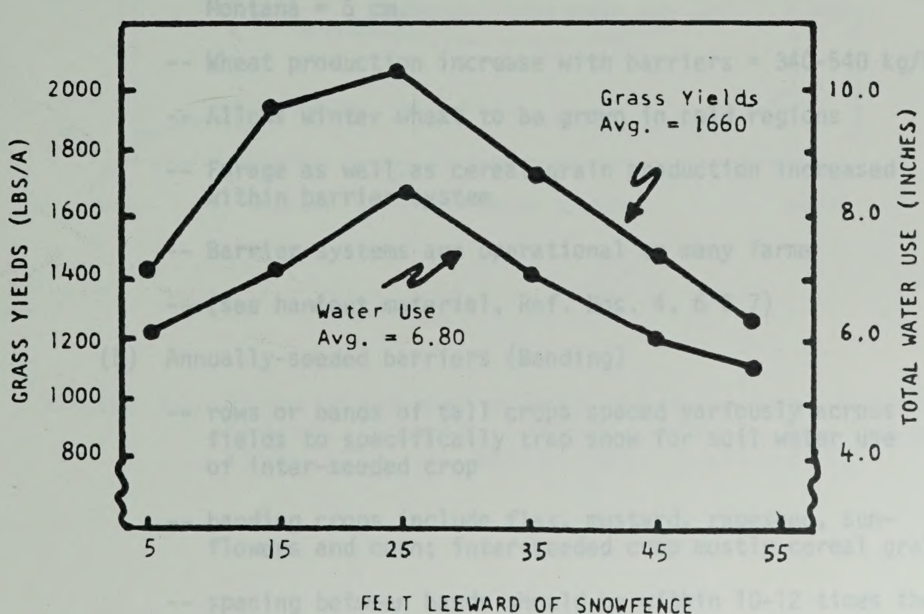


Fig. 9. Relationship of total water use to grass yield leeward of a wood-slat snow fence with 72% air porosity - Akron, Colorado ? (Greb 1970).

-- Field plantings consist of single or doublerow bushy species (Russian olive, caragana) along with taller species (green ash, box elder, siberian elm)

-- Zone of influence on crop yield generally extends to leeward distance 20-30 times tree height with maximum effect 10-15 tree heights

-- Although the area devoted to trees is pre-empted, total crop production in northern plains under a shelterbelt system is increased 3-4%

Fig. 10 -- Trapped snow and crop yield unevenly distributed behind windbreak (Figure 10)

-- Pruning windbreak distributes snow more evenly

Fig. 11 -- Summary of windbreak barrier on microclimate (Figure 11)

(4) Permanent grass barriers

-- Single or double rows of tall wheatgrass, wildrye or sudan grass spaced 30-50 ft apart; crop grown between rows

-- Average overwinter soil water increase near Culbertson, Montana = 5 cm.

-- Wheat production increase with barriers = 340-540 kg/ha.

-- Allows winter wheat to be grown in cold regions

-- Forage as well as cereal grain production increased within barrier system

-- Barrier systems are operational on many farms

-- (see handout material, Ref. Nos. 4, 6 & 7)

(5) Annually-seeded barriers (Banding)

-- rows or bands of tall crops spaced variously across fields to specifically trap snow for soil water use of inter-seeded crop

-- banding crops include flax, mustard, rapeseed, sunflowers and corn; inter-seeded crop mostly cereal grains

-- spacing between bands should be within 10-12 times the height of band crop

-- used operationally in USSR and USA (spacing often too wide)

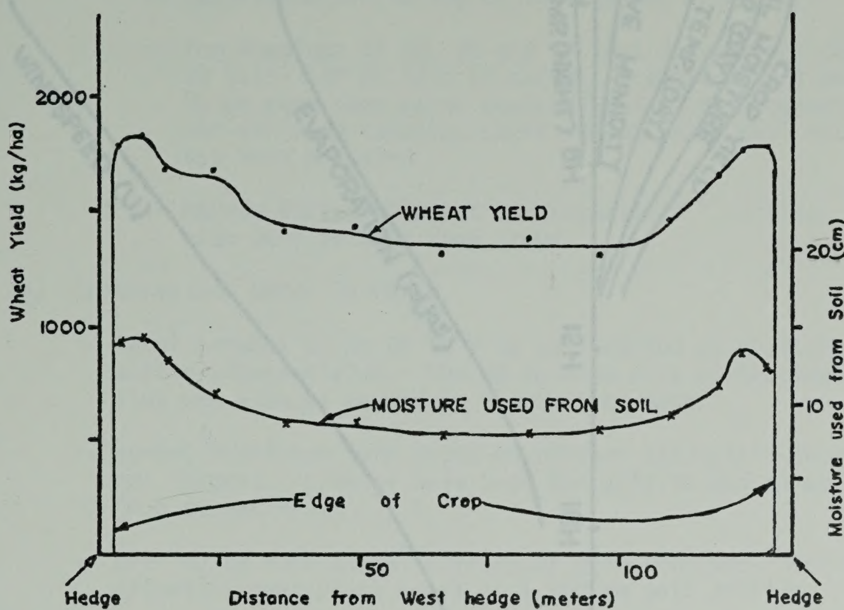
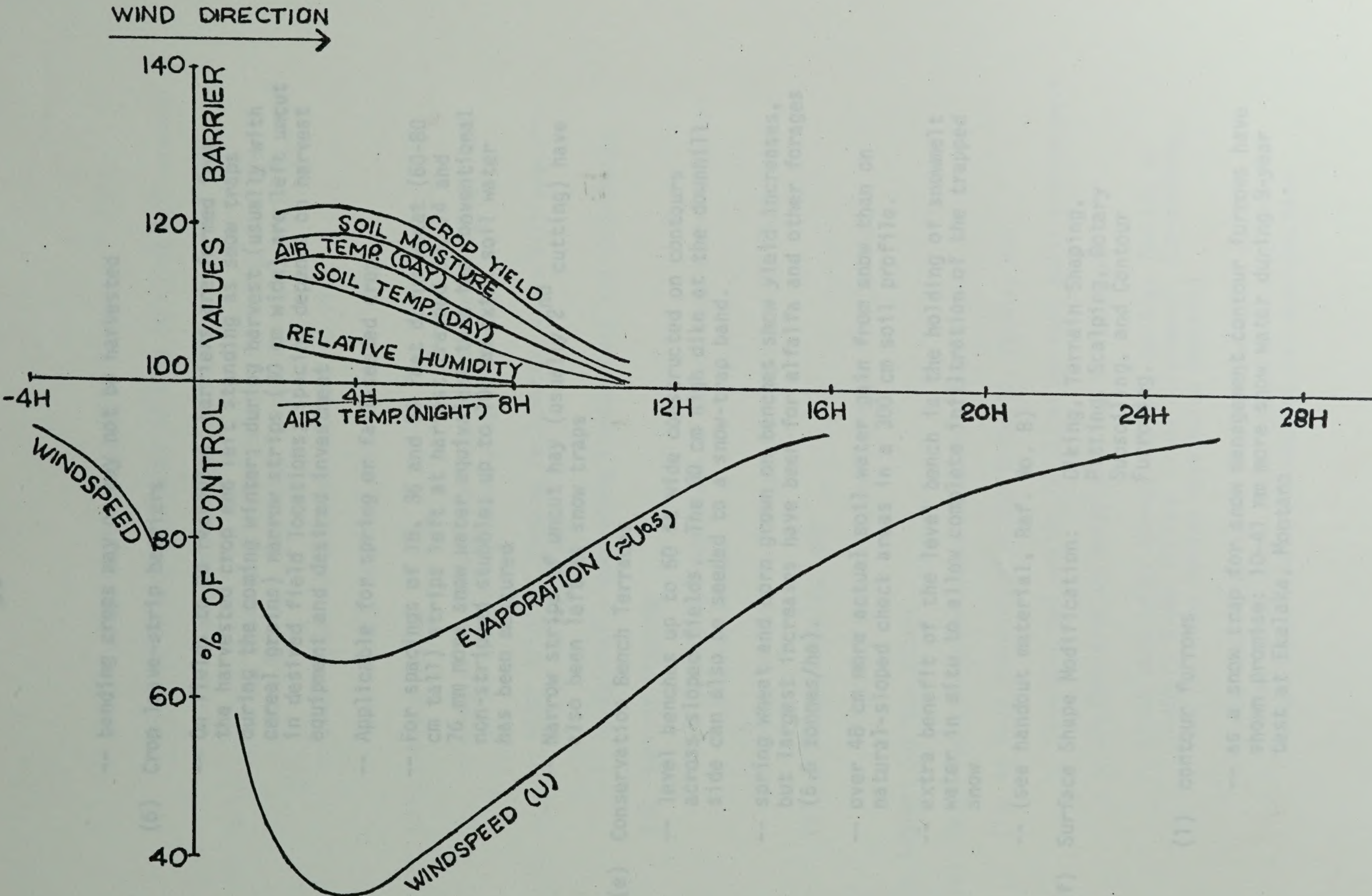


Figure 10. Wheat yield and stored moisture used between hedges, Aneroid, 1950-54. (Staple and Lehane, 1955. Can. J. Agric. Sci. 35:440-453)



Taken from: Marshall, J.K. 1967. Field Crop Abstr. 20(1):1-14.

Fig. 11. Summary diagram of the effect of barriers on micrometeorological and other indicated factors

-- banding crops may or may not be harvested

(6) Crop leave-strip barriers

-- On fields to be recropped, barriers are formed from the harvested crop and left standing as snow traps during the coming winter; during harvest (usually with cereal grains) narrow strips (30 cm wide) are left uncut in desired field locations; spacing depends on harvest equipment and desired investment

-- Applicable for spring or fall-seeded crops

-- For spacings of 18, 36 and 54 feet durum wheat (60-80 cm tall) strips left at harvest trapped 50, 74 and 76 mm more snow water equivalent than the conventional non-stripped stubble; up to 100 mm extra soil water has been measured

-- Narrow strips of uncut hay (usually 2nd cutting) have also been left as snow traps

(e) Conservation Bench Terraces

-- level benches up to 60 ft wide constructed on contours across sloped fields. The 30 cm high dike at the downhill side can also be seeded to a snow-trap band.

-- spring wheat and corn grown on benches show yield increases, but largest increases have been for alfalfa and other forages (5.6 tonnes/ha).

-- over 48 cm more actual soil water gain from snow than on natural-sloped check areas in a 300 cm soil profile.

-- extra benefit of the level bench is the holding of snowmelt water in situ to allow complete infiltration of the trapped snow

-- (see handout material, Ref. No. 8)

(f) Surface Shape Modification: Diking, Terrain Shaping, Pitting, Scalping, Rotary Subsoiling, and Contour Furrowing.

(1) contour furrows

-- as a snow trap for snow management contour furrows have shown promise: 10-41 mm more snow water during 9-year test at Ekalaka, Montana

-- proper construction required

-- also holds snowmelt water on-site to allow infiltration

-- works to ameliorate high sodic-soils

-- forage production under contour furrowing also has shown increase over that in non-furrowed condition

-- under trial at Colorado reclamation site

-- (see handout material, No. 9)

(2) contour dikes

-- similar to contour furrows, except deeper furrows and taller ridges to increase surface roughness

-- under trial at Wyoming reclamation sites with specific aim of managing snow

-- occasionally used along highway cuts and embankments

(3) terrain shaping

-- at present not practiced to effect snow control, except in highway design

-- holds promise in reclamation but requires study

(4) pitting, scalping, etc.

-- value for snow management not yet established

II-2 To Augment Surface Waters

(a) Water harvesting for stock ponds and rural supply

(1) by snow trapping with shelterbelts, fences, etc.

-- retarding melt-water infiltration into soils advantageous

-- surface erosion protection may be required

-- stock pond water harvesting by snow-trap fencing on Boundary Ridge (Poison Creek Allotment), BLM-Wyoming, Rock Springs; upwind vegetation modified

-- stock tank water harvesting by fencing in eastern Montana using butyl rubber ground cover, nylon-reinforced butyl rubber storage bag and watering tank

(2) by terrain shaping and designed surface modifications

-- snow collects in a snow catchment area with low infiltration potential and is routed to desired storage

(b) Water harvesting for wildlife, water-fowl and fish

-- terrain shaping used at mine in North Dakota to create pond for water-fowl

-- fencing can augment the terrain snow trapping

-- amount of runoff to pond will vary as natural snow traps develop and transpiring vegetation becomes established

-- wildlife can be watered by facilities as described in II-2(a)

(c) Snowcover to insulate crops against cold air

Fig 12 -- insulative property of snow against low air temperatures (Figure 12)

-- crops benefited include: alfalfa, fall rye, winter wheat, tree seedings, etc.

-- trap snow by any method, but low vegetative barriers and previous crop stubble probably best; a uniform snowcover is desired

-- winter survival equal to some function of snowcover

II-3 To Deflect or Transfer Snow

(a) Away from roads and structures

-- by terrain shaping

Fig 13 -- by deflector or blower fences (Figure 13)

- by collection fences or snowplowing or vegetative barriers situated upwind to trap snow before arrival at road or structure

(b) To prevent snow accumulation over land sensitive to surface water erosion

-- protect by collection barriers located well upwind

-- reduce surface roughness over such land

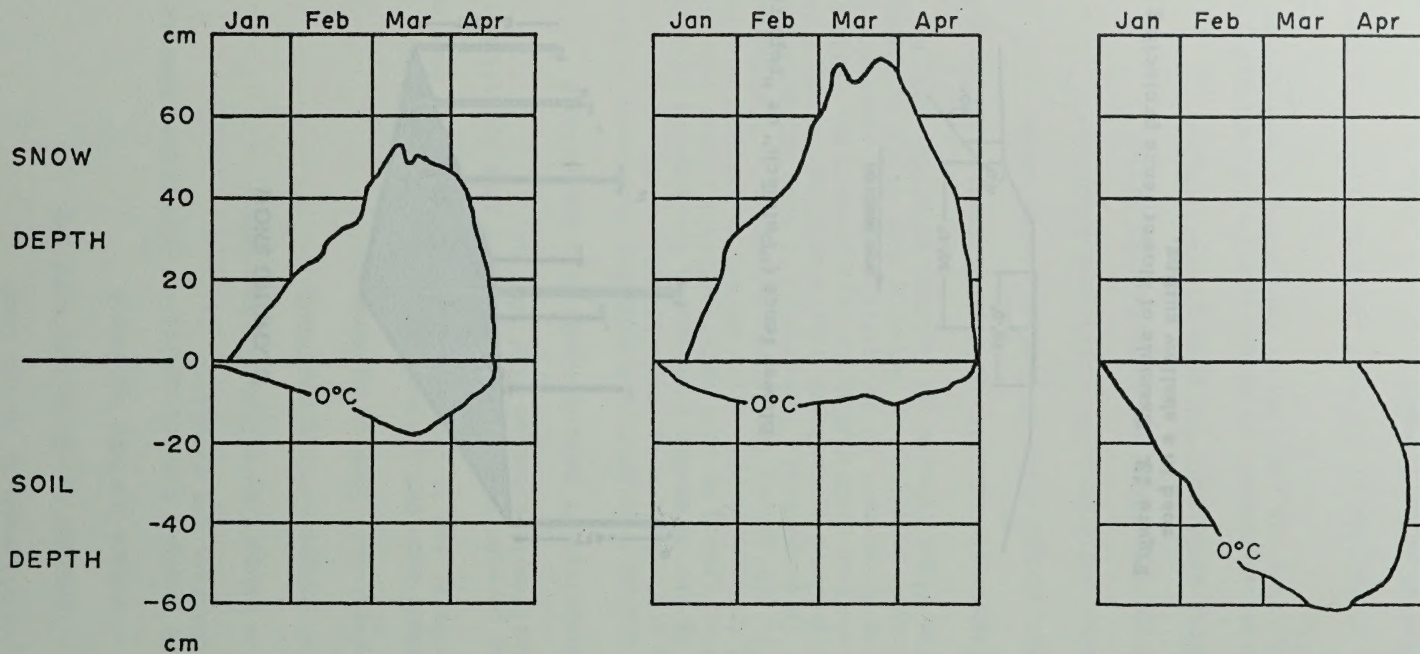
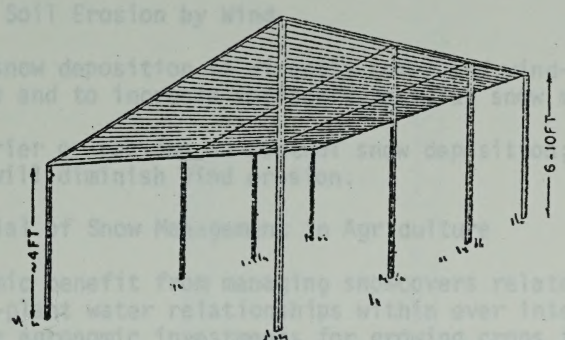


Figure 12. Snow depths over three test plots and the 0°C frost lines in the sub-surface soil for the 1951-52 Winter in southern Finland (Taken from Ylimäki, Aarre. 1962. The effect of snow cover on temperature conditions in the soil and over-wintering of field crops. Annales Agriculturae Fenniae, 1:192-216.)

BLOWING SNOW



Blower fence ("Pultdäch" or "pupitre").

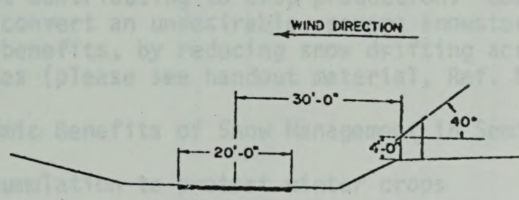


Figure 13. Example of blower fence protecting a road in a shallow cutting.

(c) To prevent snow accumulation over known recharge zones contributing to saline seeps

-- protect by collection barriers

-- reduce surface roughness

(d) To prevent snow accumulation over sites where soil water contents are excessive

-- protect by collection barriers

-- reduce surface roughness

II-4 To Prevent Soil Erosion by Wind

-- Induce snow deposition to directly cover and wind-protect soil surfaces and to increase surface wetness as snow melts

-- Use barrier or residue to control snow deposition; barrier itself will diminish wind erosion.

III. Economic Potential of Snow Management in Agriculture

The major economic benefit from managing snowcovers relates to the need for optimizing soil-plant water relationships within ever intensive cropping systems. As the agronomic investments for growing crops increase, limits to production caused by soil water deficits become less tolerable. Snow management to augment soil water offers an attractive alternative to investments in irrigation facilities dependent on limited surface water supplies. In comparison, investments in snow management are very low, yet they offer dryland agriculture supplemental water which normally would evaporate without contributing to crop production. Concurrently, snow control acts to convert an undesirable, severe snowstorm into an event with direct economic benefits, by reducing snow drifting across roads, towns and construction sites (please see handout material, Ref. No. 10).

Potential Agronomic Benefits of Snow Management in Semiarid Regions

-- Snowcover accumulation to protect winter crops

-- Soil water enrichment for continuous cropping

-- Soil water enrichment to increase crop yields

-- Soil water enrichment for crop diversification

-- Soil water enrichment to reduce costs of fertilizer and energy inputs by permitting the addition of forage and nitrification crops into the rotation

-- Better protection of the soil resource especially against winter winds

-- Reduction of major floods

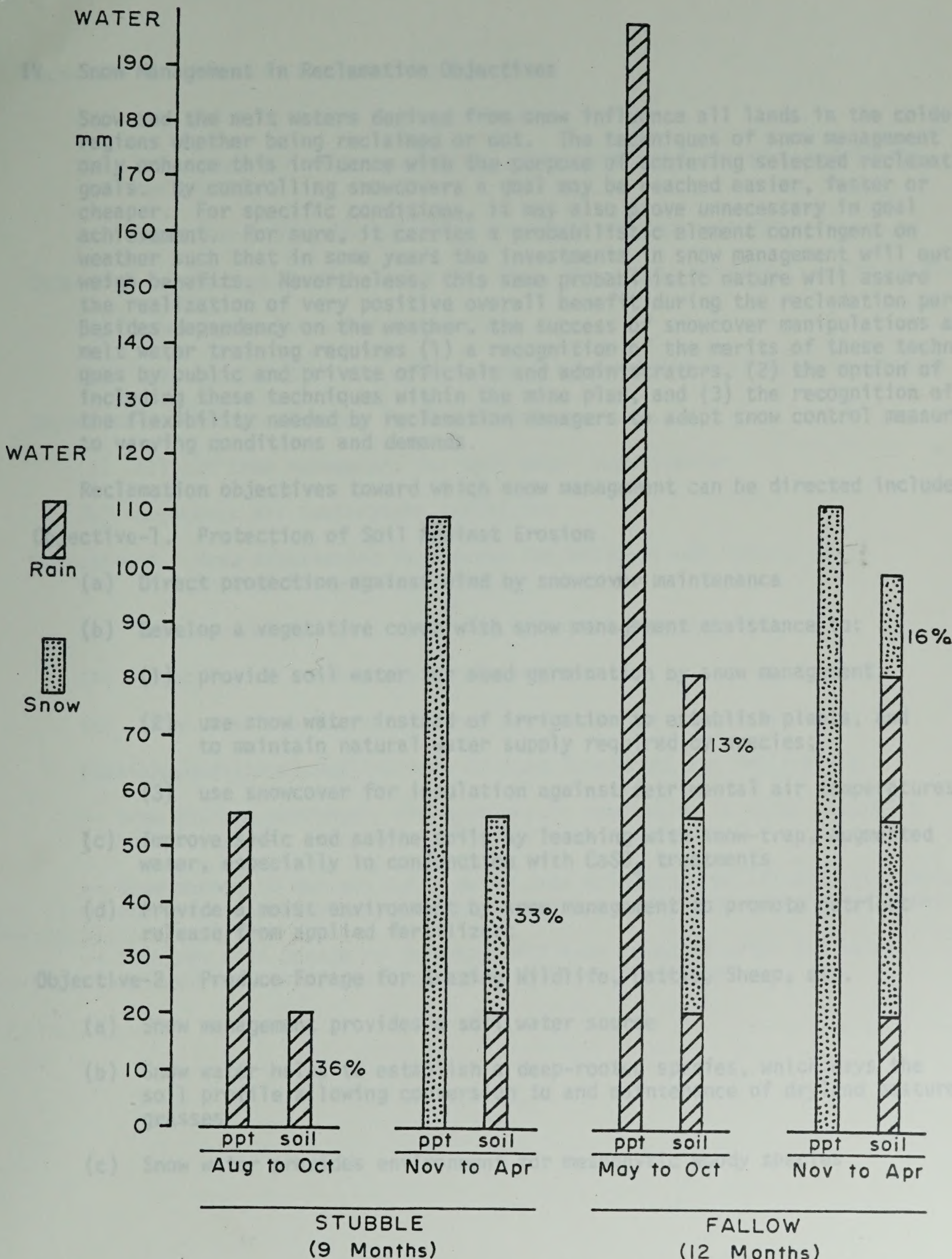


Figure 14. Average precipitation (ppt) and accumulated soil water (soil) gains during each of the four periods of a 21-month summerfallow showing respective water conservation percentages. Data from 6 to 10 locations in southwestern Saskatchewan, 1939-42, 1944-50. (Taken from Staple and Lehane. 1952. Scientific Agriculture 32:36-47)

IV. Snow Management in Reclamation Objectives

Snow and the melt waters derived from snow influence all lands in the colder regions whether being reclaimed or not. The techniques of snow management only enhance this influence with the purpose of achieving selected reclamation goals. By controlling snowcovers a goal may be reached easier, faster or cheaper. For specific conditions, it may also prove unnecessary in goal achievement. For sure, it carries a probabilistic element contingent on weather such that in some years the investments in snow management will outweigh benefits. Nevertheless, this same probabilistic nature will assure the realization of very positive overall benefit during the reclamation period. Besides dependency on the weather, the success of snowcover manipulations and melt water training requires (1) a recognition of the merits of these techniques by public and private officials and administrators, (2) the option of including these techniques within the mine plan, and (3) the recognition of the flexibility needed by reclamation managers to adapt snow control measures to varying conditions and demands.

Reclamation objectives toward which snow management can be directed include:

Objective-1. Protection of Soil Against Erosion

(a) Direct protection against wind by snowcover maintenance

(b) Develop a vegetative cover with snow management assistance to:

(1) provide soil water for seed germination by snow management;

(2) use snow water instead of irrigation to establish plants, and to maintain natural water supply required by species;

(3) use snowcover for insulation against detrimental air temperatures

(c) Improve sodic and saline soils by leaching with snow-trap, augmented water, especially in conjunction with $CaSO_4$ treatments

(d) Provide a moist environment by snow management to promote nutrient release from applied fertilizers

Objective-2. Produce Forage for Grazing Wildlife, Cattle, Sheep, etc.

(a) Snow management provides a soil water source

(b) Snow water helps to establish a deep-rooted species, which drys the soil profile allowing conversion to and maintenance of dryland pasture grasses

(c) Snow water provides environment for mesophytic woody species

Objective-3. Produce Cultivated Dryland Crops

(a) Snow water to assist seed germination

(b) Snow water for soil reserves to allow continuous cropping and faster reclamation

(c) Snowcover protection of crops from cold air temperatures

Objective-4. Produce Surface Water for Fish, Waterfowl, Wildlife, and Stock Ponds

(a) Snow management water harvesting

(b) Snow accumulation and water control in providing desired microclimates

Objective-5. Produce Forages for Hay or Silage

(a) All-out snow management for soil water augmentation

(b) Snowcover air temperature insulation

Objective-6. Grow Arborescent Vegetation for Wildlife and Scenery as in Natural Woody Draws

(a) Snow control for soil water and ephemeral stream water

(b) Promotion of a snow-related microclimate

(c) Snow coverings to protect tree seedlings from over-eager wildlife

Possible Additional Applications of Snow Management for Reclamation

-- Grow desired mesophytic and hydrophytic vegetation in sites naturally more zerophytic using water added by snow management

-- Snow manage to harvest extra water over selected, specifically designed, and purposely constructed sites to serve as ground water recharge zones

-- Snow and soil manage to harvest water over selected areas for water delivery to crop-production areas by water spreading

General Outline

SNOW MANAGEMENT APPLIED TO THE RECLAMATION OF

SURFACE-MINED LANDS

Billings Seminar
November 1979

I. Principles of Snow Management

I-1. Definition

Snow management is the art and science of utilizing or manipulating the snow resource for human benefit.

Applied to most surface-mine reclamation problems, snow management will usually require the snow-laden wind to preferentially deposit all or part of its transported load over selected locations; it may also involve the reduction of sublimation from wind-transported snow; in addition it may promote or retard the infiltration of snowmelt waters into the soil or spoil cover and conversely, it may increase or decrease runoff thereby affecting drainage and erosion.

I-2. Probabilistic Nature of the Forces which Effect Snow Management

An important element of successful snow management is the realization that control over the occurrence and timing of snow transport and deposition is weather dominated; it must be recognized that some efforts at managing the snow for reclamation objectives will fail. For one, the large quantities of snow required dictate dependency on wind forces; if winds of speeds sufficient to promote transport do not occur with a certain regularity snow management practices fail. Obviously, the merits of initiating any snow management practice are inversely proportional to the probability of failure times the cost/benefit ratio of that practice.

I-3. Location and Weather Potential for Snow Management in Surface Coal-Mined Reclamation.

(a) Location of mid-continent coal resources (Figure 1).

(b) The mid-continental, semi-arid region.

The need for snow management for mine-land reclamation is greatest where water is in short supply. It happens that large deposits of coal, whose removal appears feasible by surface mining, are located in a large mid-continental, water-deficient region (Figure 2). A measure of the potential water-deficit can be obtained by comparing the mean annual values of precipitation and Class A pan evaporation measurements. If the latter exceeds the former by two-fold, aridity is indicated. The recognition of this semi-arid region is further strengthened with the knowledge that the region's water deficits are even greater during the summer. During winter, precipitation is often in excess of evaporation, which indicates a potential source of water for summer use by storing snowmelt in soil reserves.

(c) Availability of snow for management.

It also happens that the total annual quantity of snow falling on the coal lands of the northern Great Plains (Figure 3) is a significant water resource. The quantity of water from just one snowfall distributed to a depth of 6 inches (15 cm) over these northern plains equals the mean annual flow of water leaving the Great Lakes system via the St. Lawrence River. A resource in the form of frozen prairie water is indeed available for management and for subsequent use for many purposes, for example, water supply, agricultural production and others.

(d) Prairie winds.

Winter winds over the mid-continental coal lands are primarily

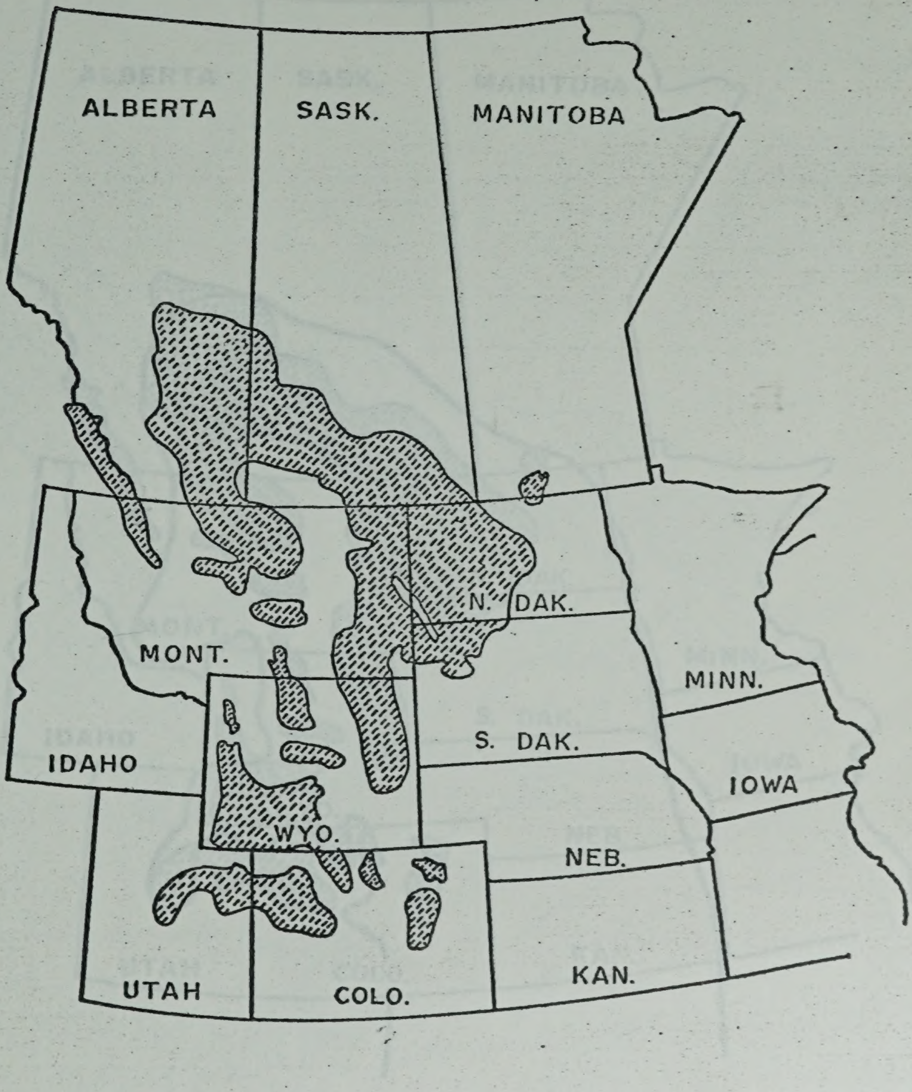


Figure 1. Location of mid-continental coal resources of all types.

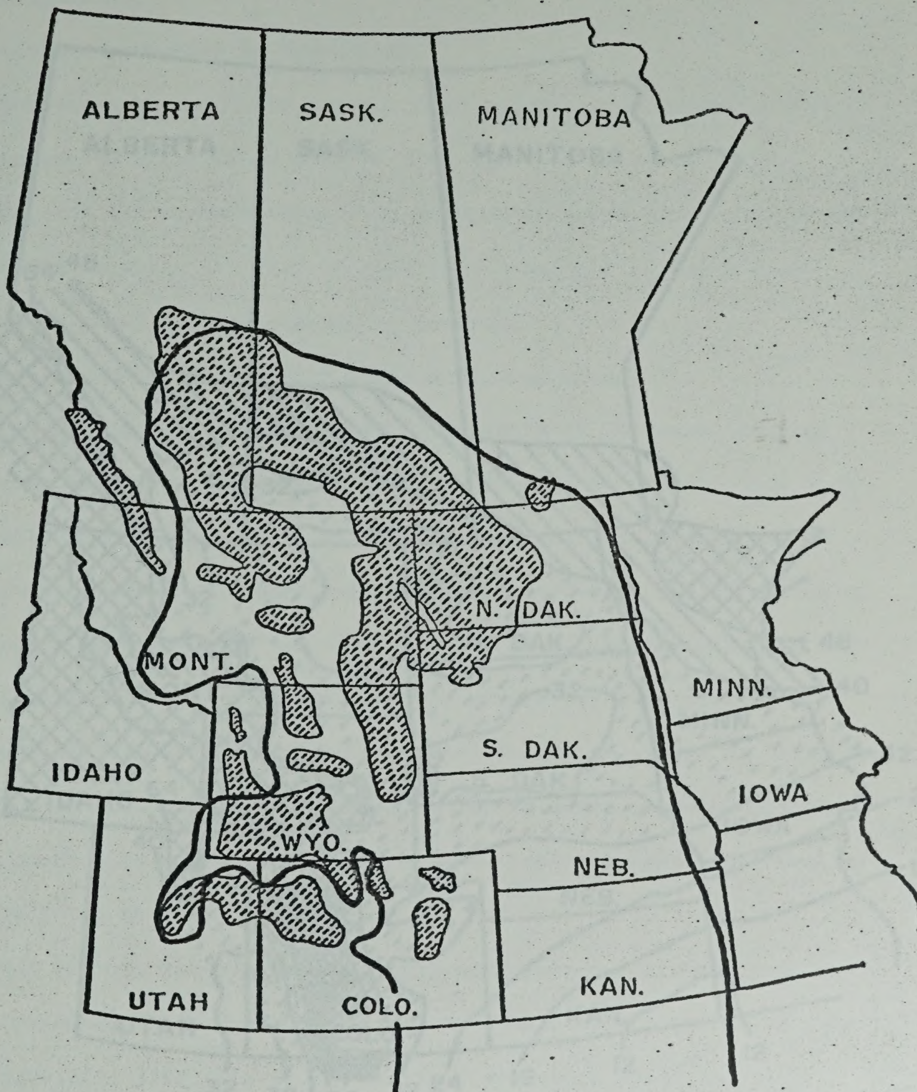


Figure 2. Location of mid-continental coal resources and the mid-continental region of large annual water deficits (as bounded by the heavy line) where the mean annual evaporation from Class A Pans exceeds the mean annual precipitation by two fold or more.

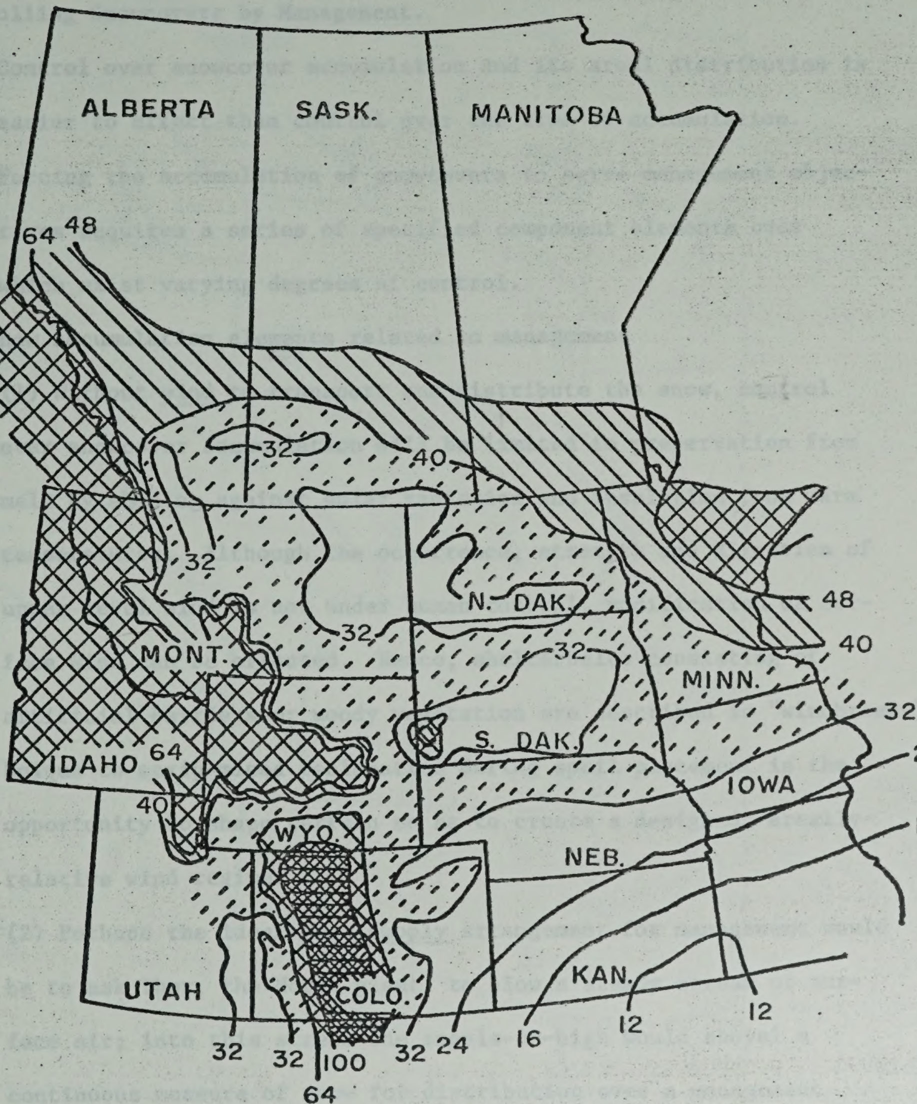


Figure 3. Mean annual snowfall over the mid-continental region in inches of snow depth assuming no melt or sublimation.

associated with large-scale frontal systems. The existence of extensive, prairie-vegetated plains typical of the region further promotes the windy conditions for which the region is known (Figure 4).

I-4. Controlling Snowcovers by Management.

Control over snowcover accumulation and its areal distribution is easier to effect than control over the time of accumulation. Forcing the accumulation of snowcovers to serve management objectives requires a series of specified component elements over which exist varying degrees of control.

(a) Snow accumulation elements related to management

(1) Without wind to transport and distribute the snow, control over snowcover accumulation will be limited to preservation from melt by shading against solar radiation and insulation from warm temperatures. Although the occurrence, strength and direction of upper level wind is not under human control, modification of surface wind can be effected. Hence, shelterbelts consisting of artificial barriers or woody vegetation are described as "windbreaks". Unique to strip-mined reclamation during spoil placement is the opportunity to shape terrain so as to create a designed, areally-relative wind regime.

(2) Perhaps the ideal snow supply arrangement for management would be to ask Thor, the Norse giant, to blow a steady stream of surface air; into this stream the angels-on-high would shovel a continuous measure of snow for distribution over a management area. Sometimes the weather gods do indeed supply a snowfall of this sort, that is, snow falls steadily into and moves horizontally with a surface wind. Often however, the highest wind

PREVAILING DIRECTION AND MEAN SPEED (mph) OF WIND
JANUARY

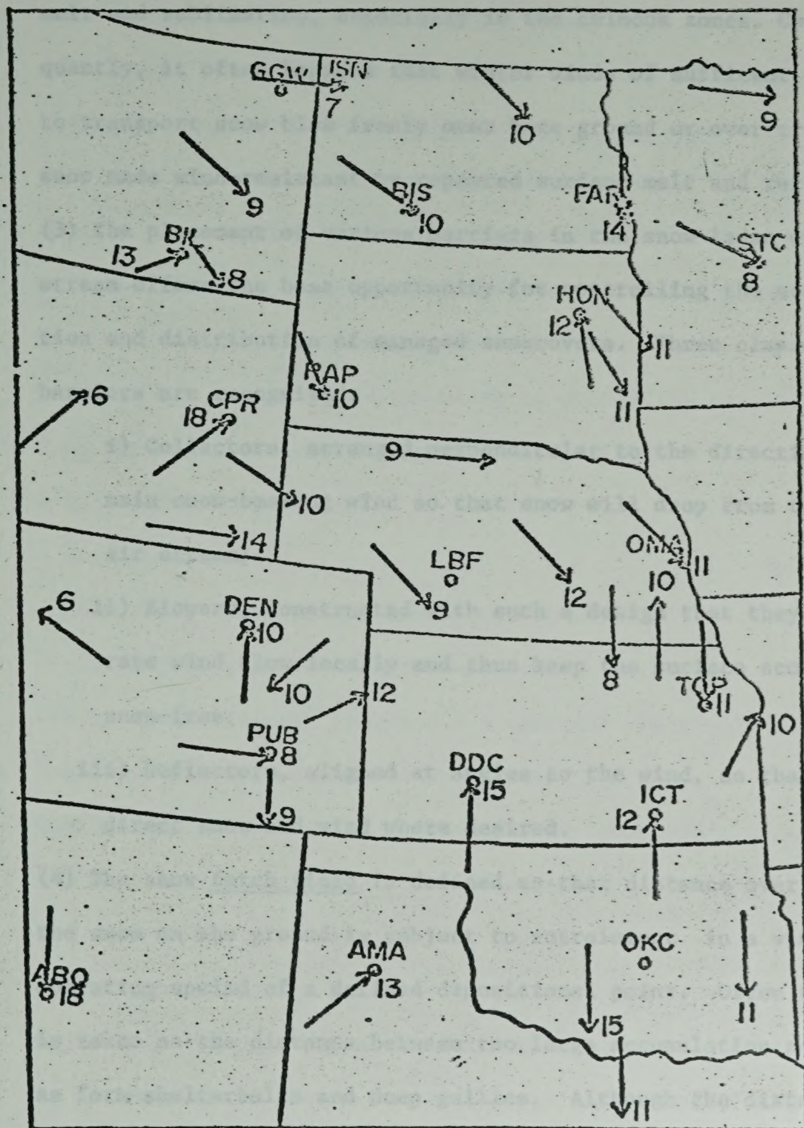


Figure 4. (Taken from Grant, L.O. and J. Ramirez, 1975. Climatological aspects of snow on the Great Plains. Great Plains Agricultural Council, Pub.73, p.219, Snow Management on the Great Plains. Univ. of Nebraska, Lincoln.)

speeds occur after the bulk of snow has fallen. Snow transport then includes an entrainment process to obtain the snow lying on the ground. Snowcovers are also susceptible to depredation by melt and sublimation, especially in the chinook zones. Consequently, it often happens that winter winds of sufficent speeds to transport snow blow freely over bare ground or over crusted snow made wind-resistant by repeated surface melt and refreeze.

(3) The placement of various barriers in the snow-laden wind stream offers the best opportunity for controlling the accumulation and distribution of managed snowcovers. Three classes of barriers are recognized:

i) Collectors, arranged perpendicular to the direction of the main snow-bearing wind so that snow will drop from the passing air stream;

ii) Blowers, constructed with such a design that they accelerate wind flow locally and thus keep the surface scoured snow-free;

iii) Deflectors, aligned at angles to the wind, so that they direct snow and wind where desired.

(4) The snow fetch field is defined as that distance over which the snow on the ground is subject to entrainment in a wind stream operating upwind of a defined depositional point. Often the fetch is taken as the distance between two large accumulation zones such as farm shelterbelts and deep gullies. Although the distance between these zones might be exceedingly great, one cannot assume that all the snow in the fetch will travel the entire distance; every particle of wind-transported snow will, under most weather conditions, lose mass during its travel. Ron Tabler (1972, 1975)

has defined maximum transport distances over which an average size snow particle will completely sublimate while air-borne. For study sites in Wyoming under most weather conditions, this transport distance is close to 3 km (1.8 miles).

(5) Control over the snowcover to realize some management objective may require continued maintenance of the snow to be effective. Use of the snowcover to insulate vegetation against cold ambient temperatures requires such maintenance. Short of shading or insulating the snow, loss by melt is not easily prevented. However, holding a desired snowcover in place against erosion by wind is more easily accomplished using protective barriers.

(b) Some Mechanics of Snow Transport and Deposition

- wind velocity profile
- surface elements
- snow load, gravity, and upward air currents
- wind velocity profile over a barrier
- wind speed + static pressure = a constant (Bernoulli's principle)

(c) Snowcover Deposition Induced by Terrain

Snowdrift profiles can be predicted from topographic data using the empirically derived regression equation

$$Y = 0.25X_1 + 0.55X_2 + 0.15X_3 + 0.05X_4$$

(if measured X_2, X_3, X_4 <-20, set X_2, X_3, X_4 = -20)

where Y is the snow slope (%) over the main portion of the drift, X_1 is the average ground slope (%) over a distance of 45 m (150 ft) upwind of the catchment, and X_2, X_3 and X_4 are the ground slopes (%) over distances of 0-15 m (0-50 ft), 15-30 m (50-100 ft), and 30-44 m (100-150 ft) downwind of the trap lip. Slopes upward in the direction of the wind are taken as positive, and downward

slopes as negative. A dynamic extension of this method can be used to predict the snow slope at any point on a drift, thus allowing snow profiles to be constructed across natural terrain transects extending for long distances. More detailed information, and a program listing for the Hewlett-Packard 9820A calculator, is given in the following reference:

Tabler, Ronald D., 1975. Predicting profiles of snowdrifts in topographic catchments. Proc. Western Snow Conf. 43:87-97.

The Wyoming State Highway Department is using this snowdrift prediction technique for road design (the snowdrift prediction model is included as an option in the earthwork computer program).

(d) Snowcover Deposition Induced by Vegetation

- woody draws
- shelterbelts
- brush
- standing crop residues

(e) Snowcover Accumulation According to Landscapes

Figure 5 - for prairie environments

(f) Surface Roughness Concept

- nature is rough
- applicable to reclamation

I-5 Infiltration of Snowmelt Water into Soil or Spoil

- some management objectives aim to retard infiltration, e.g. snow water harvesting for surface storage
- most management objectives, especially involving soil water storage require maximum infiltration
- Figure 6 conceptually outlines infiltration of meltwater into frozen media

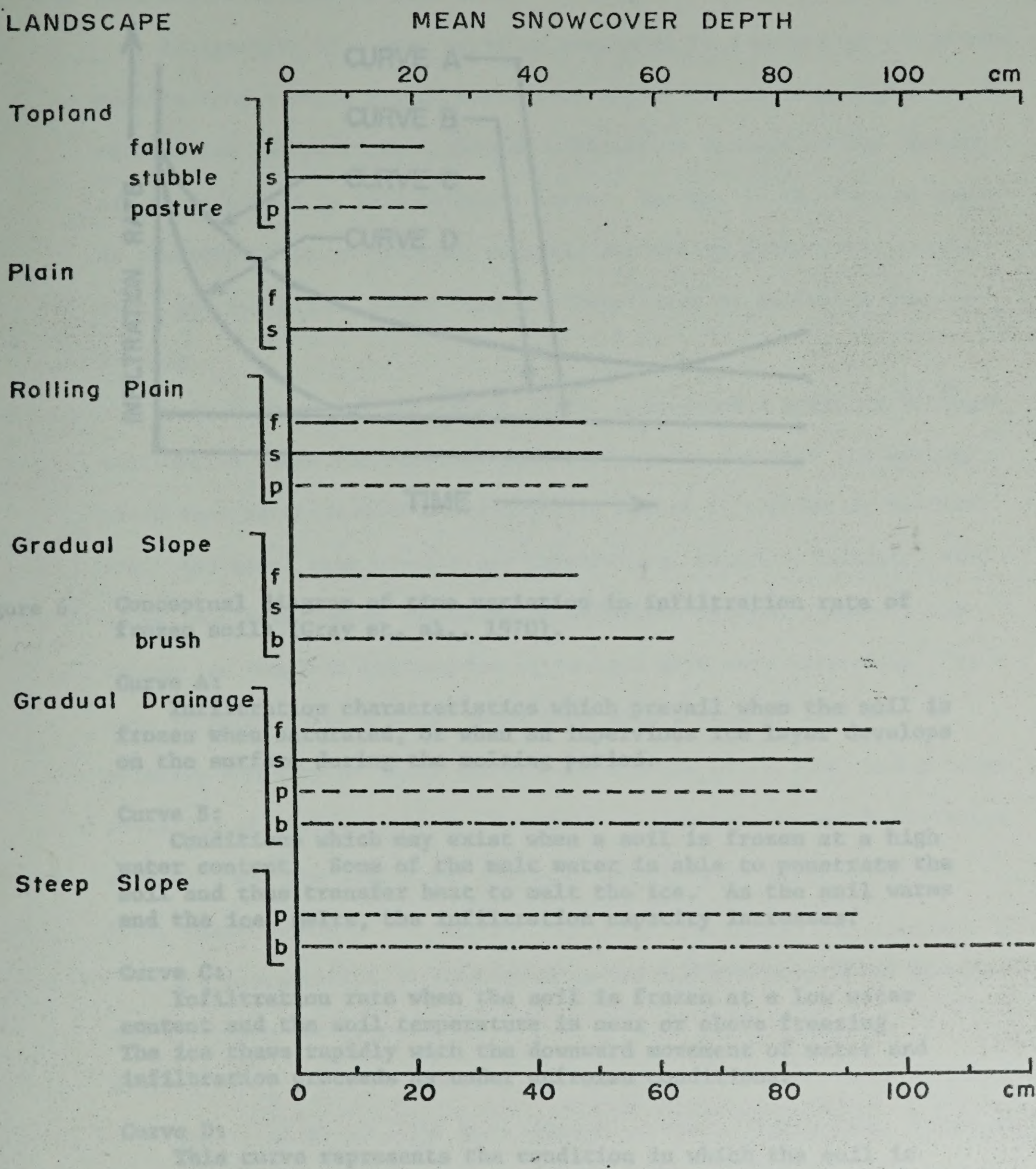


Figure 5. Average depth of snow covering selected prairie landscapes, from March 1974 snow surveys, Creighton Watershed, Southwestern Saskatchewan.

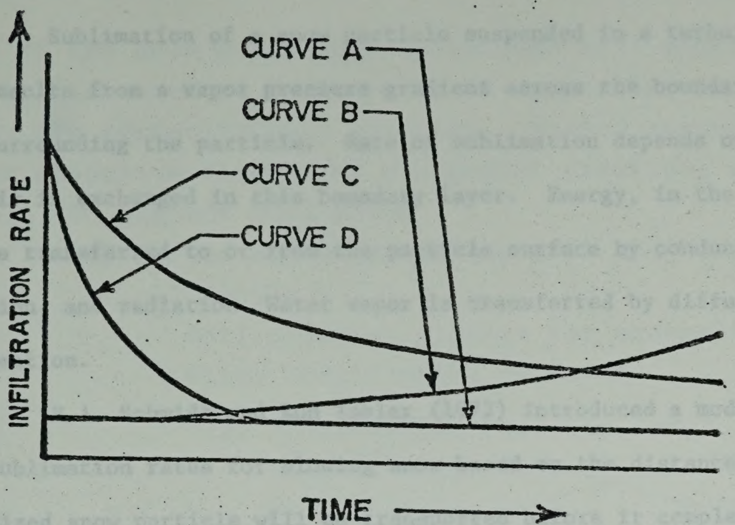


Figure 6. **Conceptual diagram of time variation in infiltration rate of frozen soils (Gray et. al., 1970).**

Curve A:

Infiltration characteristics which prevail when the soil is frozen when saturated, or when an impervious ice layer develops on the surface during the melting period.

Curve B:

Conditions which may exist when a soil is frozen at a high water content. Some of the melt water is able to penetrate the soil and thus transfer heat to melt the ice. As the soil warms and the ice melts, the infiltration capacity increases.

Curve C:

Infiltration rate when the soil is frozen at a low water content and the soil temperature is near or above freezing. The ice thaws rapidly with the downward movement of water and infiltration proceeds as under unfrozen conditions.

Curve D:

This curve represents the condition in which the soil is frozen at a low water content but the soil temperature at the time of snowmelt is below freezing. Water entering the soil is frozen and movement is inhibited.

Reference: Gray, Donald M., Donald I. Norum and John M. Wigham, 1970. Infiltration and the physics of flow of water through porous media. Section V. Handbook on the Principles of Hydrology, Secretariat Canadian National Committee for the International Hydrologic Decade, NRC, Ottawa, Canada, p. 5.15.

I-6. Sublimation of Wind-Carried Snow

Sublimation of a snow particle suspended in a turbulent air stream results from a vapor pressure gradient across the boundary layer surrounding the particle. Rate of sublimation depends on how rapidly air is exchanged in this boundary layer. Energy, in the form of heat, is transferred to or from the particle surface by conduction, convection, and radiation. Water vapor is transferred by diffusion and convection.

R.A. Schmidt and Ron Tabler (1972) introduced a model to estimate sublimation rates for blowing snow based on the distance the average sized snow particle will be transported before it completely sublimates. The model uses on-site air temperature, relative humidity, wind speed, and total solar radiation to calculate maximum transport distances for complete sublimation of various size snow particles. For a site in Wyoming and weather conditions with a wind of 11.8 m/s, a relative humidity of 72.1% and air temperature of -7.7 °C, and a solar radiation of 16.9 cal/cm^2 hr, complete sublimation transport distances were 457, 899 and 1421 m for particle diameters of 0.01, 0.015 and 0.02, respectively.

For presentation of this model as refined and simplified consult the following reference:

Tabler, R.D., 1975. Estimating the transport and evaporation of blowing snow. pp.85-104. In: Snow Manage. on Great Plains Symp. (Bismark, N. Dak., July 1975) Proc. Great Plains Agric. Counc. Publ.73, 186p.

III. Snow Management Practices Currently Available for Application to the Reclamation of Surface-Mined Lands

Many of the snow management techniques most applicable to reclamation evolved in response to agricultural needs, and thus, are agriculturally oriented. Listed according to their objective these snow management practices are:

III-1. To Augment Soil Water

(a) Spread and maintain top soil and subsoil over all spoils

-- Soil provides storage for snowmelt water

-- Water infiltration promoted

e.g. infiltration rate (in./hr.)	1st hr	2nd hr
without topsoil	2.88	6.47
with topsoil	0.42	1.93

-- Soil wedge over spoils showed increasing benefits as thickness of soil increased up to 28 in. for either 8 or 24 in. of top soil (Table 1)

(b) Maintenance of crop residues overwinter (crop stubble management)

-- Trap snow with crop stubble

e.g. (1) wheat stubble at Swift Current, Saskatchewan(Table 2)

(2) sunflower stubble traps more than wheat stubble (in Sask. 32 cm for sunflower and 15 cm for wheat)

-- taller stubble most effective

(At Williston North Dakota)

Wheat Residue Height		Snow Water Equivalent	Available Soil water
winter 1976-77	0 (cm.)	2.0 (cm.)	1.4 (cm/120cm
	18	3.6	2.4
	36	7.4	4.7
winter 1977-78	0	2.3	4.3
	15	4.3	5.7
	30	6.8	6.6

-- grasses grown in contour rows

Table 1 Yield of First Harvest of Several Crops as Affected by Thickness of Subsoil and Topsoil Spread Over Sodic (SAR = 26) Mine Spoils.

Topsoil Thickness inches	Subsoil thickness, inches							
	4	12	20	28	36	44	52	60
	A. Spring wheat yields, bu/acre							
0	11.9	15.8	17.8	19.2	18.8	18.6	19.6	18.6
8	23.9	28.5	29.1	28.9	29.5	29.0	30.2	28.6
24	29.2	30.0	30.5	30.5	28.8	29.9	30.9	31.7
Mixed	15.7	20.0	21.9	22.4	23.2	22.0	22.5	21.6
	B. Alfalfa (first cut), tons/acre dry matter							
0	0.048	0.20	0.36	0.43	0.37	0.31	0.37	0.39
8	0.32	0.28	0.56	0.51	0.60	0.57	0.52	0.54
24	0.41	0.42	0.44	0.47	0.41	0.59	0.54	0.48
Mixed	0.057	0.17	0.36	0.43	0.55	0.47	0.51	0.54
	C. Crested wheatgrass, tons/acre dry matter							
0	0.87	1.12	1.29	1.36	1.50	1.24	1.55	1.43
8	1.26	1.43	1.45	1.65	1.48	1.40	1.55	1.41
24	1.24	1.31	1.41	1.45	1.37	1.46	1.26	1.38
Mixed	0.71	1.12	1.50	1.45	1.57	1.33	1.47	1.50
	D. "Native" grasses,[1] tons/acre dry matter							
0	0.008	0.068	0.053	0.081	0.14	0.12	0.15	0.13
8	0.21	0.27	0.39	0.46	0.47	0.39	0.35	0.29
24	0.15	0.060	0.22	0.19	0.16	0.11	0.12	0.14
Mixed	0.00	0.003	0.038	0.073	0.046	0.038	0.15	0.16

[1]Blue grama and sideoats grama.

Table 2. Conservation of Soil Water over-winter at Swift Current

Year	Snow depth (March)		Soil water conserved	
	Stubble	fallow	Stubble	fallow
1936-7	12.7 cm	2.5 cm	2.0	0
1937-8				
1938-39	10.2	3.8	4.3	-1.8
1939-40				
1940-41	0	0	0.76	1.02
1941-42	14.0	5.1	6.4	2.8

-- Snow from taller stubble may also increase runoff

At Mandan, N. Dakota

wheat stubble height (in.)	0	10	20
runoff (% of snow cover)	57	67	69

-- Fertilization produces taller plants, but reduces water use per unit production

e.g. spring wheat in Saskatchewan

	stubble	fallow
	(mg grain/g H_2O)	
No fertilizer	0.59	0.66
Fertilizer	0.75	0.82

-- Alternate height double swathing

Cereal crops are often cut and windrowed prior to combining. Cutting swaths at alternate heights of 9 and 6 inches increased snow water catch by 0.6 in. over a uniform height stubble of 6 in.

-- Straight combining leaves a taller stubble

-- Fall cultivation generally reduces field snowcover and soil water reserves (Table 3)

-- Grazing intensity of pastures and range; less grazing leaves taller plants:
(see handout material)

(c) Non-Vegetative Barriers

(1) Field Fences

-- Will trap snow if placed downwind of a snow-fetch

-- Brush, wood-on-wire, all wood, plastic net

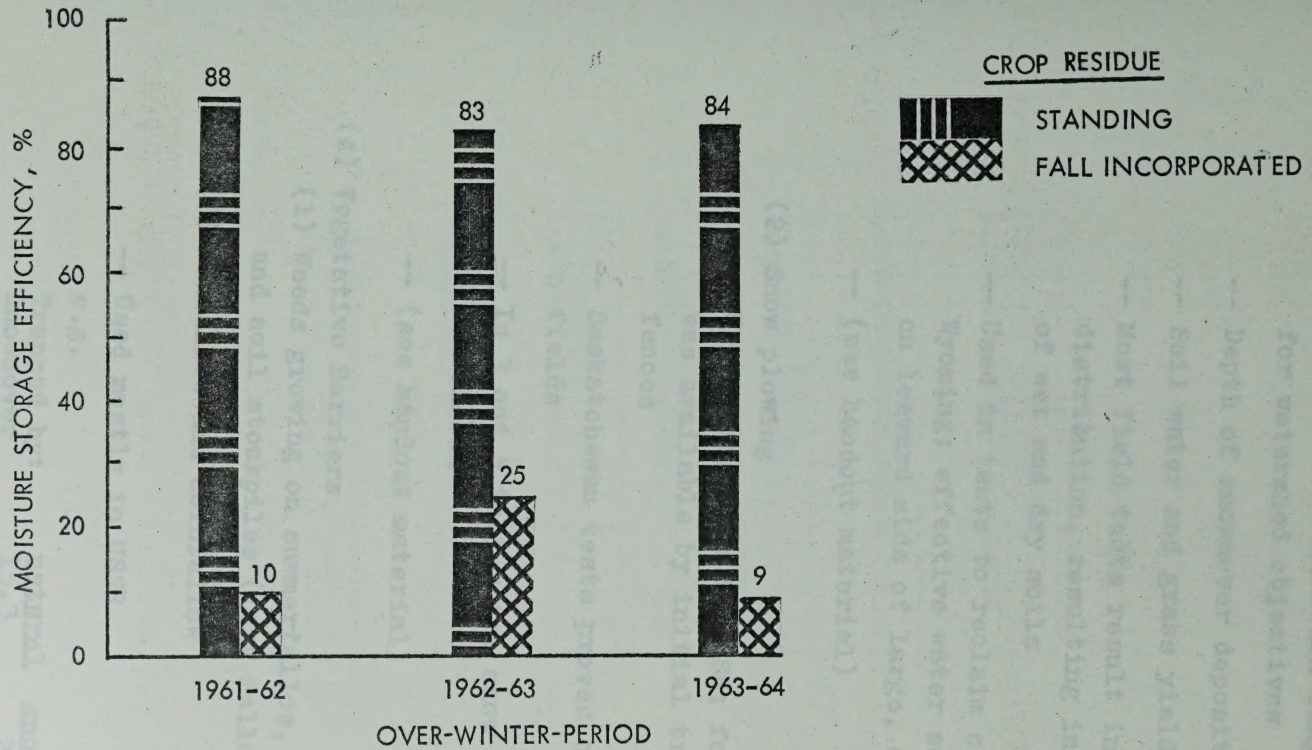
-- Laid out in chess-board pattern in Kazakhstan S.S.R.

-- Tried many times in experiment, rarely used operationally

TABLE 3.

EFFECT OF SURFACE RESIDUE ON THE STORAGE OF SOIL WATER FROM SNOW (November 15 through March 31), NORTH PLATTE, NEBRASKA (from Smika and Whitfield, 1966).

Over-winter period	Residue	Available soil water to 1.83 m depth, cm		Precip-itation cm	Storage Efficiency %
		Nov 15	March 31		
1961-62	Standing	9.4	14.5	5.8	88.2
	Fall incorporated	9.9	10.5		10.0
1962-63	Standing	13.9	18.8	5.8	83.3
	Fall incorporated	15.3	16.8		25.3
1963-64	Standing	11.2	16.8	6.7	83.6
	Fall incorporated	9.9	10.5		8.8
1964-65	Standing	14.2	19.3	3.6	140.6
	Fall incorporated	14.2	10.4		-105.6



EFFECT OF SURFACE RESIDUE ON THE MOISTURE STORAGE FROM SNOW, NORTH PLATTE, NEBRASKA (NOVEMBER 15 through MARCH 31)
(Smika and Whitfield, 1966)

-- Used in some mountain range allotments and for watershed objectives

-- Depth of snowcover deposit around fences (Fig.7)

-- Soil water and grass yield behind fences (Fig.8&9

-- Most field tests result in non-uniform snow distribution, resulting in alternate strips of wet and dry soils

-- Used in tests to reclaim coal mine spoils in Wyoming; effective water source when placed on leeward side of large, open, level areas

-- (see handout material)

(2) Snow plowing

-- Used occasionly in USSR; found best when snow was available by initial trapping with brush fences

-- Saskatchewan tests proved best in stubble fields

-- In 3 out 5 test years, snow plowing was not successful

-- (see handout material)

(d) Vegetative Barriers

(1) Weeds growing on summerfallow, reclamation site, and soil stockpiles (lazy fallow)

(2) Sunfallow and cornfallow

-- Used mostly in USSR

e.g.

Trapped by:	natural	snowplow (cm.)	sunflower fence
Snowcover	15.3	24	42

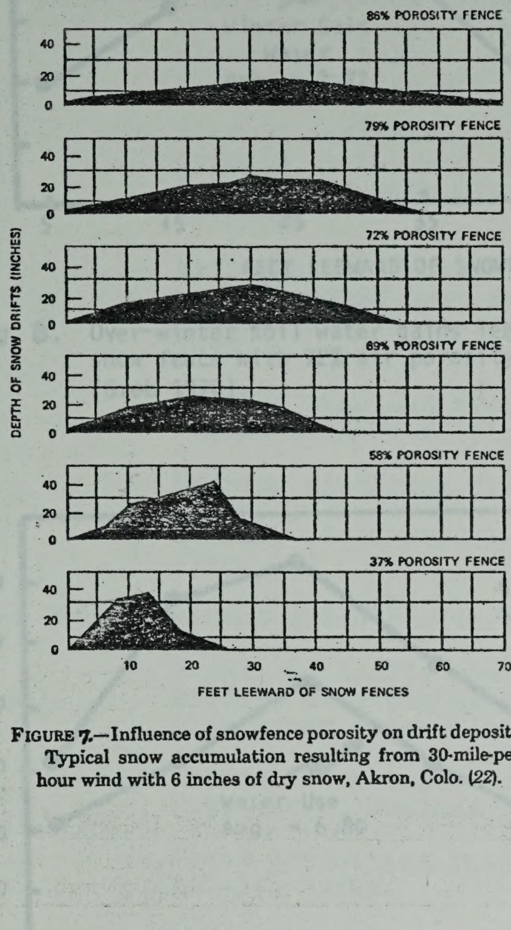


FIGURE 7.—Influence of snowfence porosity on drift deposits. Typical snow accumulation resulting from 30-mile-per-hour wind with 6 inches of dry snow, Akron, Colo. (22).

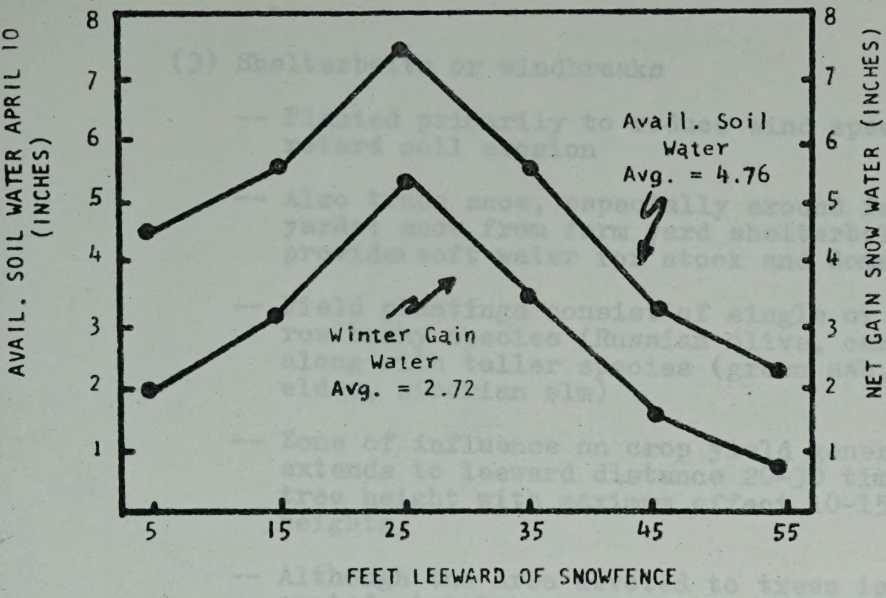


Fig. 8. Over-winter soil water gains leeward of a wood-slat snow fence with 72% air porosity - Akron, Colorado (Greb 1970).

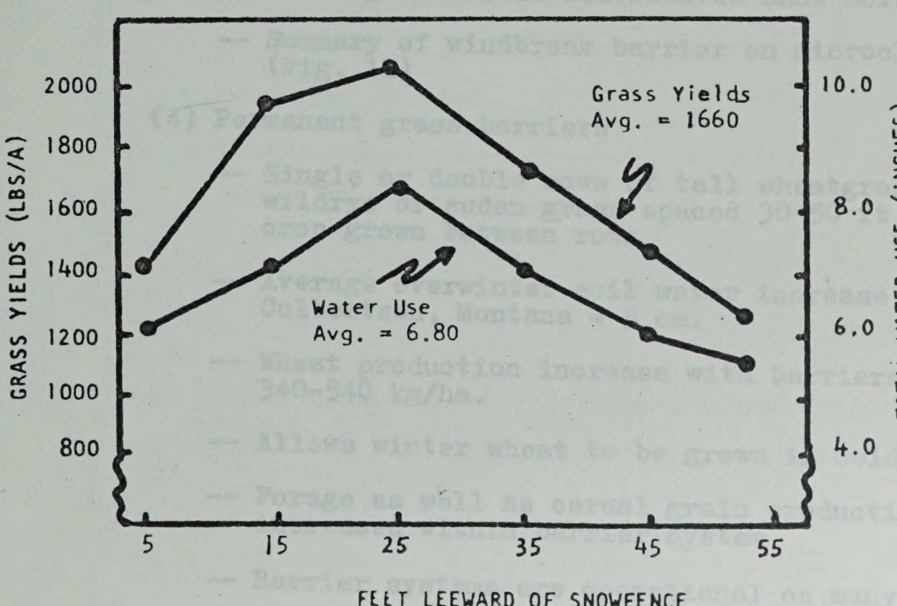


Fig. 9. Relationship of total water use to grass yield leeward of a wood-slat snow fence with 72% air porosity - Akron, Colorado (Greb 1970).

(3) Shelterbelts or windbreaks

-- Planted primarily to reduce wind speeds and retard soil erosion

-- Also traps snow, especially around farm yards; snow from farm yard shelterbelts provides soft water for stock and domestic use

-- Field plantings consist of single or double-row bushy species (Russian olive, caragana) along with taller species (green ash, box elder, siberian elm)

-- Zone of influence on crop yield generally extends to leeward distance 20-30 times tree height with maximum effect 10-15 tree heights.

-- Although the area devoted to trees is pre-empted, total crop production in northern plains under a shelterbelt system is increased 3-4%.

-- Trapped snow and crop yield unevenly distributed behind windbreak (Fig. 10)

-- Pruning windbreak distributes snow more evenly

-- Summary of windbreak barrier on microclimate (Fig. 11)

(4) Permanent grass barriers

-- Single or double rows of tall wheatgrass, wildrye or sudan grass spaced 30-50 ft apart; crop grown between rows

-- Average overwinter soil water increase near Culbertson, Montana = 5 cm.

-- Wheat production increase with barriers = 340-540 kg/ha.

-- Allows winter wheat to be grown in cold regions

-- Forage as well as cereal grain production increased within barrier system

-- Barrier systems are operational on many farms

-- (see handout material)

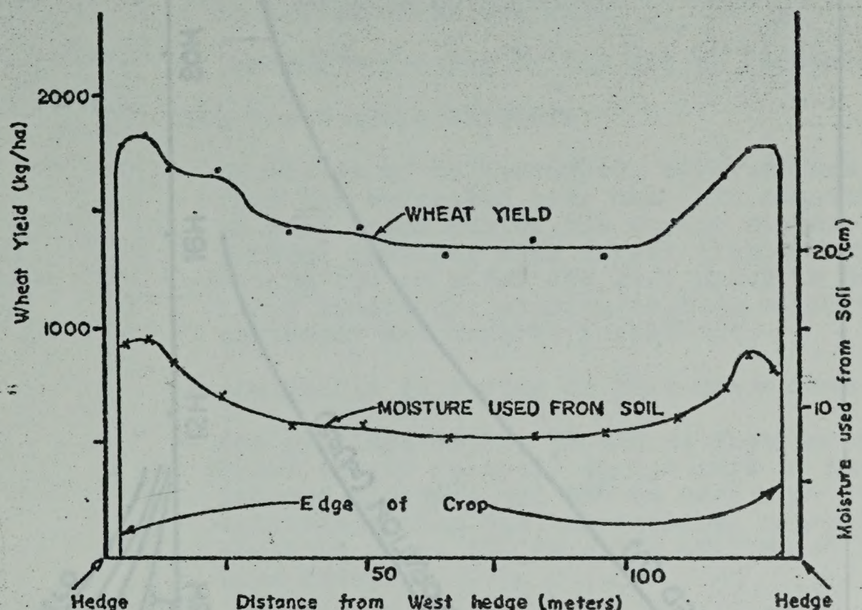


Figure 10. Wheat yield and stored moisture used between hedges, Aneroid, 1950-54. (Staple and Lehane, 1955. Can. J. Agric. Sci. 35:440-453)

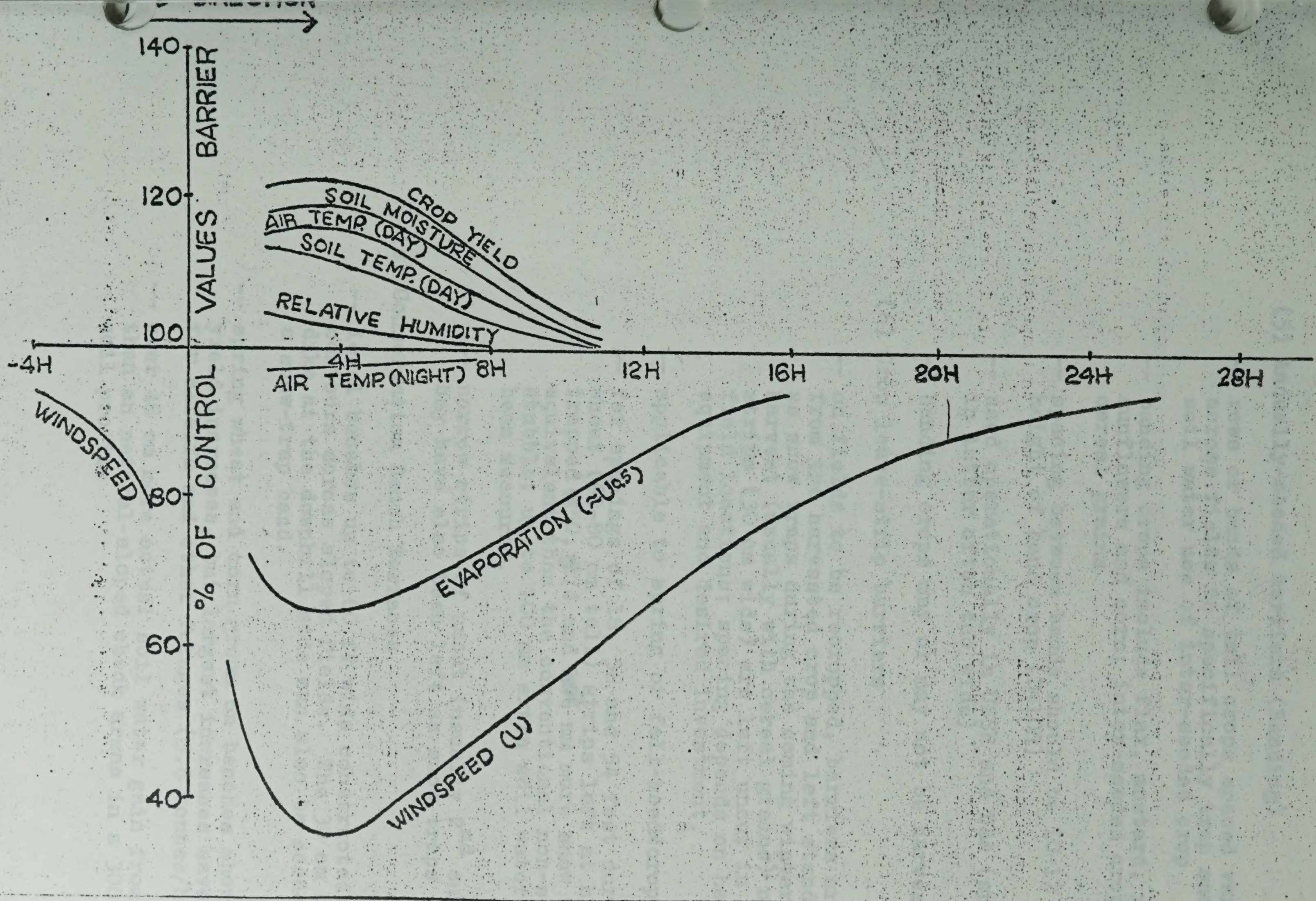


Figure 11. Summary diagram of the effect of barriers on micrometeorological and other indicated factors

(5) Annually-seeded barriers (Banding)

- -- rows or bands of tall crops spaced variously across fields to specifically trap snow for soil water use of inter-seeded crop
- -- banding crops include flax, mustard, rapeseed, sunflowers and corn; inter-seeded crop mostly cereal grains
- -- spacing between bands should be 10-12 times the height of band crop (D=10H)
- -- used operationally in USSR and USA (spacing in latter often too wide)
- -- banding crops may or may not be harvested

(6) Crop leave-strip barriers

- -- on fields to be recropped, barriers are formed from the harvested crop and left standing as snow traps during the coming winter; during harvest (usually with cereal grains) narrow strips (30 cm wide) are left uncut in desired field locations; spacing depends on harvest equipment and desired investment.
- -- applicable to spring or fall-seeded crops
- -- for spacings of 18, 36 and 54 feet durum wheat (60-80 cm tall) strips left at harvest trapped 50, 74 and 76 mm more snow water equivalent than the conventional non-stripped stubble; up to 100 mm extra soil water has been measured.
- -- narrow strips of uncut (usually 2nd cutting) hay have also been left as snow traps

(e) Conservation Bench Terraces

- -- level benches up to 60 ft wide constructed on contours across sloped fields. The 30 cm high dike at the downhill side can also be seeded to a snow-trap band.
- -- spring wheat and corn grown on benches show yield increases, but largest increases have been for alfalfa and other forages (5.6 tonnes/ha)
- -- over 48 cm more actual soil water gain from snow than on natural-sloped check areas in a 300 cm soil profile

-- extra benefit of the level bench is the holding of snowmelt water in situ to allow complete infiltration of the trapped snow

-- (see handout material)

(f) Surface Shape Modification: Diking, Terrain Shaping, Pitting, Scalping, Rotary Subsoiling, and Contour Furrowing.

(1) contour furrows

-- as a snow trap for snow management contour furrows have shown promise: 10-41 mm more snow water during 9-year test at Ekalaka, Montana

-- proper construction required

-- also holds snowmelt water on-site to allow infiltration

-- works to ameliorate high sodic-soils

-- forage production under contour furrowing also has shown increase over that in non-furrowed condition

-- (see handout material)

(2) contour dikes

-- similar to contour furrows, except deeper furrows and taller ridges to increase surface roughness

-- under trial at Wyoming reclamation sites with specific aim of managing snow

-- occasionally used along highway cuts and embankments

(3) terrain shaping

-- at present not practiced to effect snow control, except in highway design

-- holds promise in reclamation but requires study

(4) pitting, scalping, etc.

-- value for snow management not yet established

III-2. To Augment Surface Waters

(a) water harvesting for stock ponds and rural supply

(1) by snow trapping with shelterbelts, fences, etc.

-- retarding melt-water infiltration into soils advantageous

-- surface erosion protection may be required

-- stock pond water harvesting by snow-trap fencing on Boundary Ridge (Poison Creek Allotment), BLM-Wyoming, Rock Springs; upwind vegetation modified

-- stock tank water harvesting by fencing in eastern Montana using butyl rubber ground cover, nylon-reinforced butyl rubber storage bag and watering tank

(2) by terrain shaping and designed surface modifications

-- snow collects in a snow catchment area with low infiltration potential and is routed to desired storage

(b) water harvesting for wildlife, water-fowl and fish
-- terrain shaping used at mine in North Dakata to create pond for water-fowl

-- fencing can augment the terrain snow trapping

-- amount of runoff to pond will vary as natural snow traps develop and transpiring vegetation becomes established

-- wildlife can be watered by facilities as described in III-2(a)

(c) snowcover to insulate crops against cold air

-- insulative property of snow against low air temperatures (Fig. 12)

-- crops benefited include: alfalfa, fall rye, winter wheat, tree seedings, etc.

-- trap snow by any method, but low vegetative barriers and previous crop stubble probably best; a uniform snowcover is desired

-- winter survival equal to some function of snowcover

III-3. To Deflect or Transfer Snow

(a) away from roads and structures

-- by terrain shaping

-- by deflector or blower fences (Fig. 13)

-- by collection fences or snowplowing or vegetative barriers situated upwind to trap snow before arrival at road or structure

(b) to prevent snow accumulation over land sensitive to surface water erosion

-- protect by collection barriers located well upwind

-- reduce surface roughness over such land

(c) to prevent snow accumulation over known recharge zones contributing to saline seeps

-- protect by collection barriers

-- reduce surface roughness

(d) to prevent snow accumulation over sites where soil water contents are excessive

-- protect by collection barriers

-- reduce surface roughness

III-4. To Prevent Soil Erosion by Wind

-- induce snow deposition to directly cover and wind-protect soil surfaces and to increase surface wetness as snow melts

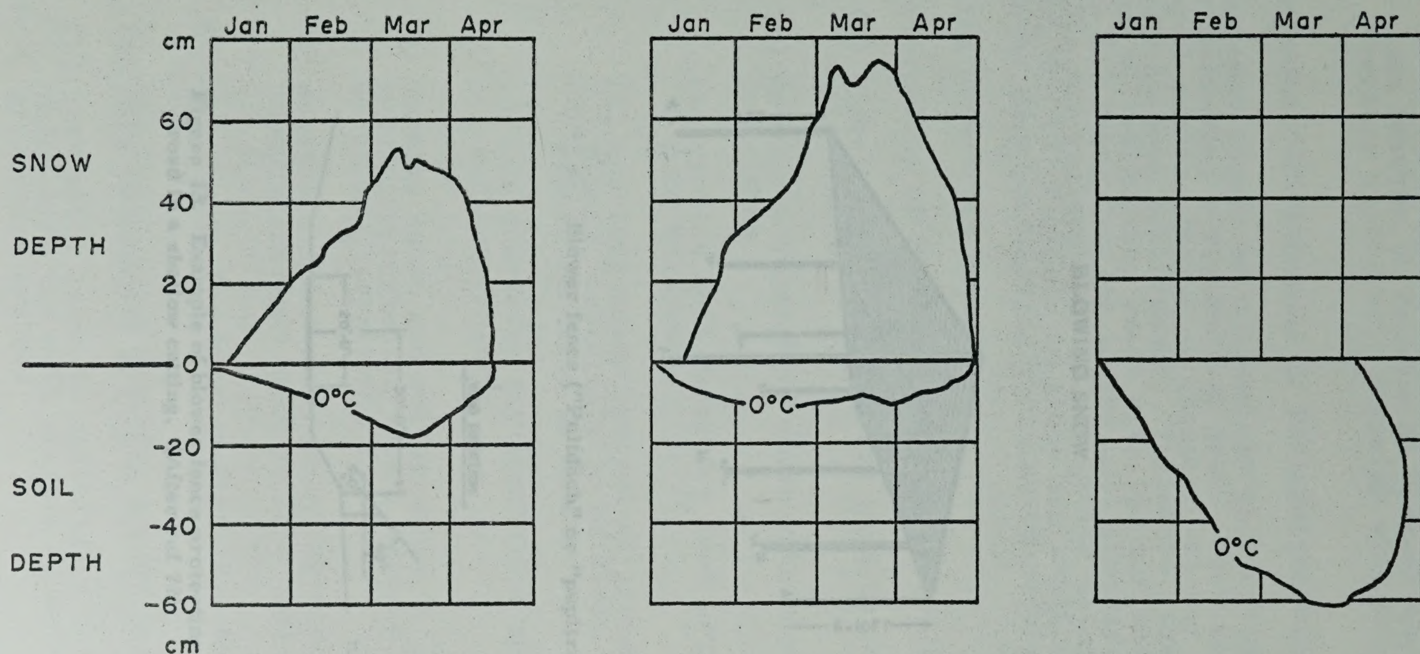
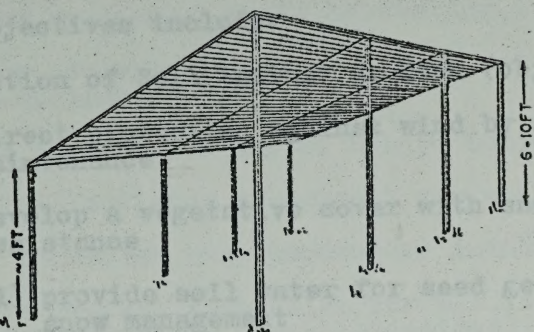


Figure 12. Snow depths over three test plots and the 0°C frost lines in the sub-surface soil for the 1951-52 Winter in southern Finland (Taken from Ylimäki, Aarre. 1962. The effect of snow cover on temperature conditions in the soil and over-wintering of field crops. Annales Agriculturae Fenniae, 1:192-216.)

BLOWING SNOW



Blower fence ("Pultdäch" or "pupitre").

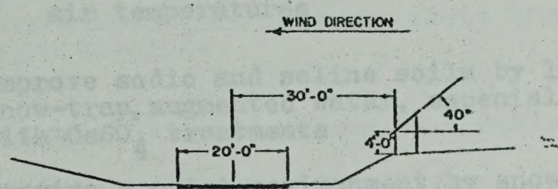


Figure 13. Example of blower fence protecting a road in a shallow cutting. (After ref 72).

-- use barrier or residue to control snow deposition; barrier itself will diminish wind erosion

IV. Snow Management Contributions To Reclamation Objectives

Snow management serves as a technical tool or instrument to assist in achieving a reclamation goal. Snow control may help reach a goal easier, faster or cheaper. It may also prove unnecessary in goal achievement. Therefore, the value of snow management to reclamation rests with the various snow control practices (1) being familar to the coal company or consultants responsible for reclamation, (2) an option allowable by the mine plan, and (3) flexible in scope and application to be adaptable to many conflicting reclamation requirements.

Reclamation objectives include:

IV-1. Protection of Soil Against Erosion (objective)

(a) direct protection against wind by snowcover maintenance

(b) develop a vegetative cover with snow management assistance

(1) provide soil water for seed germination by snow management

(2) use snow water instead of irrigation to establish plants, especially to maintain natural water supply required by species

(3) use snowcover for insulation against detrimental air temperatures

(c) improve sodic and saline soils by leaching with snow-trap, augmented water, especially in conjunction with $CaSO_4$ treatments

(d) provide a moist environment by snow management to promote nutrient release from applied fertilizers

IV-2. Produce Forage for Grazing Wildlife, Cattle, Sheep, etc. (objective)

(a) snow management provides a soil water source

(b) snow water helps to establish a deep-rooted species, which drys the soil profile allowing maintenance of dryland grasses

(c) snow water provides environment for mesophytic woody species

IV-3. Produce Cultivated Dryland Crops (objective)

(a) snow water to assist seed germination

(b) snow water for soil reserves to allow continuous cropping and faster reclamation

(c) snowcover protection of crops from cold air temperatures

IV-4. Produce Surface Water for Fish, Waterfowl, Wildlife, and Stock ponds (objective)

(a) snow management water harvesting

(b) snow accumulation and water in providing desired microclimates

IV-5. Produce Forages for Hay or Silage (objective)

(a) by all-out snow management for soil water augmentation

(b) by snowcover air temperature insulation

IV-6. Grow Arborescent Vegetation for Wildlife and Scenery as in Natural Woody Draws (objective)

(a) by using snow control for soil water and ephemeral stream water

(b) by providing snow-related microclimate

(c) over-winter tree seedling protection from over-eagar wildlife

V. Potential Snow Management Applications in a Reclamation Context

-- Increase snow accumulation and melt water infiltration as part of surface roughness promotion; review of applicable techniques

-- Leaching of sodic soils and spoils by water harvesting

-- Grow desired meso- and hydro-phytic vegetation in sites naturally more zerophytic using water added by snow management

-- Snow manage to harvest extra water over selected, specifically designed and constructed ground water recharge zones

-- Snow and soil manage to harvest water over selected areas for water delivery to crop production areas by water spreading

-- Other useful applications

VI. Economics of Snow Management in Mine-land Reclamation

VII. Improvements

VII-1. In Developing Applicable Snow Management Techniques to Realize Reclamation Objectives

VII-2. In Exchanging Snow Management Know-how for Reclamation Problems between Reclamation Managers , Researchers and Specialists

Snow as a resources
- under-developed, least appreciated
- combined with wind, it's potential as a renewable nat. res. increases tremendously

Background for contract
- Bray + Stepp 40 yrs combined exp.
- Del - princ. applied to a working farm enterprise

PROGRESS REPORT

PROJECT: SNOW MANAGEMENT FOR MINED-
LAND RECLAMATION AREAS.

By

H. Steppuhn
Don W. Gray

Division of Hydrology
College of Engineering
University of Saskatchewan
Saskatoon, Saskatchewan
Canada S7N OWO

[illegible]
- [illegible]
- combined with [illegible]
[illegible]

Background for contract
- [illegible]
- [illegible]

TO: Bureau of Land Management, U.S. Dept. of the Interior, Denver Service Center, Denver Federal Center, Building 50, Denver, Colorado 80225

FROM: Division of Hydrology, College of Engineering, University of Saskatchewan, Saskatoon, Saskatchewan S7N OWO

The enclosed material summarizes the work undertaken and the results obtained to date in connection with the contract "SNOW MANAGEMENT FOR MINED-LAND RECLAMATION AREAS": Contract YA-512-CT9-168. Details are presented which outline the site visitation completed and list the abstracts of most publications reviewed that are relevant to the project objective.

Respectfully submitted

H. Stepphn
D. W. Gray

Sept. 18, 1979

THE MANAGEMENT OF SNOWCOVERS
IN THE RECLAMATION OF SURFACE-MINED LANDS:
REVIEW OF LITERATURE AND CURRENT RESEARCH

PURPOSE AND OVERVIEW

Snow has been the object of programmed management in transportation, flood control, agriculture, forestry, winter recreation, watersheds, and engineering works. Generally management programs attempt (1) to prevent snow from drifting, accumulating, and obstructing vision across roadways, raillines, airstrips, etc., and (2) to accumulate snow in desired locations such as required for winter roads (used in cold climates), for upstream retention of potential flood waters, and for enhancement of snow to provide cold temperature insulation for crops and for augmenting soil waters from snowmelt.

The purpose of this review is to assess the possibility of applying snow management techniques to assist in the reclamation of surfaced-mined lands. Many of the snow management practices which have been researched and applied for these other purposes are also applicable for mined-land reclamation, as evidenced in this literature review. It serves a useful purpose to also emphasize the various conditions and relationships which give rise to the potential for snow management in a reclamation context. Problems associated with surface reclamation often relate directly to the various hydrological and climatological environments in which the reclamation crops must germinate and grow. Manipulation and inhancement of snowcovers, especially in windy regions, provide one of the few opportunities to manage water supplies for specific hydrologic purposes and conditions.

For the ease of reviewing the potential role for snow management in mined-land reclamation, a general sequence of reclamation procedures or steps might prove useful. Actual reclamation begins with removal and stockpile-storage of various topsoil and subsoil layers prior to over-burden removal. The material directly over the ore is then removed and placed in an adjacent linear pit from which the ore has already been mined. Mining proceeds laterally and continuously in this combined removal-deposition fashion where after the surface of the depositied spoil is shaped according to reclamation design and allowed to settle for at least one year. After subsidence nearly ends, stockpiled top and subsoils are distributed over the spoil and prepared for seeding of an initial or nurse cover of vegetation. As this vanguard cover becomes established, attention begins toward converting its vegetative composition to that specified by reclamation design. The transition can be rapid or slow depending on the required ecology and environmental conditions.

The five general applications of snow management for the reclamation of surface-mined lands are:

(1) to provide the critical interface water required for successful germination of seeds necessary for establishment and growth of desired vegetative covers, whether distributed over the spoil, spoil-covered top soil or the various stockpiles of soil material;

(2) to recharge the soil and spoil water for use by plants comprising the various vegetative covers required in reclamation to stabilize the surface and to re-secure the site into a productive unit;

(3) to provide a deposition of insulating snow over established plant covers susceptible to cold over-winter air temperatures;

(4) to accumulate a source of water to act as a leaching agent in sodic media to carry excessive sodium downward away from the root zone; and

(5) to cover the surface with snow in windy environments to prevent erosion.

STEP OUTLINE OF SEQUENCE OF WORK, INCLUDING CURRENT STATUS, TO FULFIL CONTACT REQUIREMENTS

Work Plan

1. Comprehensive literature search and preparation of a listing of publications and their abstracts of material relevant to the project requirements.

2. The undertaking of site visits to different mines and discussion with personnel directly involved with reclamation activities.

3. The undertaking of visit to different research centers in which snow management studies, which have potential application to surface-mine reclamation, have been or are currently undertaken.

4. Collation of the information collected from the literature review, site visits and discussions and evaluation of the potential of different snow management practices to assist in the reclamation of surface-mined areas.

5. Preparation of a final report to include:
   (a) an objective appraisal of present snow management practices to the reclamation of surface-mined areas and
   (b) recommendation of other snow management practices that need to be further researched, which offer potential in reclamation.

6. Presentation of findings at a seminar to be held in November, 1979.

Status (as of Sept. 18, 1979)

1. Completed - Items 1, 2, and 3 (above)

2. In Progress - Items 4 and 5.

ITINERARY, FIELD AND STUDY TOURS

Research Centers

(1) Northern Plains Soil and Water Research Center
Science and Education Administration (SEA)
Agricultural Research (AR), U.S. Dept. Agric.
Sidney, Montana
21 August 1979
Dr. Francis Siddoway, Director
Dr. Earl Neff, Research Engineer, Agric.
Dr. Kris Aase, Research Scientist, Soils
Dr. Ross Wight, Research Scientist, Range Mangement
Dr. Ardel Halvorson, Research Scientist, Agronomy

(2) Northern Plains Research Center
SEA-AR, U.S. D.A.
Mandan, North Dakota
22 August 1979
Dr. Al Black, Director, Agronomy
Dr. Armaud Bauer, Research SCientist, Agronomy
Dr. Fred Sandaval, Research Scientist, Soils

(3) North Dakota State University Experimental Farm
Williston, North Dakota
23 August 1979
Mr. Ernest W. French, Superintendent

(4) Research Station
Canada Dept. of Agriculture, Research Branch
Swift Current, Saskatchewan
15 August, 1979
Dr. Walt Nicholaichuk, Research Scientist, Soil and Water
Dr. Yih-wu Jame, Research Scientist, Forage, Water
Dr. James D. McElgunn, Research Scientist, Range Specialist

(5) Research Laboratory
Rocky Mountain Forest and Range Experiment Station
Laramie Wyoming
31 July 1979
Dr. R.D. Tabler, Research Hydrologist

(6) Research Unit
SEA-AR, USDA
Laramie, Wyoming
31 July 1979
Dr. Frank Rauzi, Research SCientist, Soil and Water

(7) Research Unit
SEA-AR, USDA
Fort Collins, Colorado
3 August 1979
Dr. W.O. Willis, Research Leader, Soil and Water

(8) Climatological - Reclamation Task Force (Bruce Van Haveren, Chairman)
Fort Collins, Colorado
1-2 August 1979
Dr. Thomas McKee, Colorado State Climatologist
Mr. Eugene Farmer, Research Hydrologist, Reclamation Scientist
Dr. Freeman Smith, Watershed Sciences Professor, Colorado State Univ.
Dr. Dale Hoffman, Div. of Special Studies, USBLM

(9) Division of Hydrology
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(10) Additional contacts:
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Agricultural Engineering Dept.
Univ. of Idaho
Moscow, Idaho

Mr. Wally Greb, Research Scientist
Central Plains Research Station
SEA-AR USDA
Akron, Colorado

Dr. Russ Schneider, Soil and Water Research
Soils Dept.
North Dakota State Univ.
Fargo, North Dakota

Mines and Mining Sites

(1) Souris Valley Mines, Estevan, Saskatchewan:
Mr. Gary Douglas, Reclamation Engineer, Saskatchewan Power Corporation, Regina, Sask.
20 August 1979

(2) Glenharold Mine, Consolidated Coal Co.
Stanton, N.D. Rick Williamson, Ranger Specialist
23 August 1979

(3) Indian Head Mine, North American Coal Co.
Zap, N.D. Jim Brown, Reclamation Specialist
20 August 1979

(4) Kerr Coal Mine, Kerr Coal Co.
Walden, Colorado David Kerr, Superintendent of Engineering
2 August 1979

(5) McCallum Site (Potential Coal Lease Tract)
Walden, Colorado
Bruce VanHaveren Dale Hoffman, Division of Special Studies, U.S. Bur. Land Management
2 August 1979

(6) Berthoud Site (Potential Coal Lease Tract)
Berthoud, North Dakota
Electrical Power Generating Plant (under construction)
Coal Gasification Plant (Planned)

Resource Management

(1) Montana State Office
U.S. Bureau of Land Management
Billings, Montana
16 August 1979
Mr. Mike Whittington, State Hydrologist
Mr. Larry Cary, Hydrologist U.S. Geological Survey
Mr. Fred Waldhaus, EMRIA Coordinator
Mr. Duane Whitmer, Range Scientist
Mr. Tom Yochem, Hydrologist
Mr. Dick Cleveland, Hydrologist

(2) Wyoming State Office
U.S. Bureau of Land Management
Cheyenne, Wyoming (Met in Ft. Collins, Colorado)
17 August 1979
Mr. Dick McQuisten, State Hydrologist

(3) North Dakota District
U.S. Bureau of Land Management
Dickenson, North Dakota
19-20 August 1979
Mr. Chuck Steale, District Manager
Mr. Chuck Pettee, District Hydrologist

(4) Alberta Dept. of Environment
Division of Land Conservation and Reclamation
Edmonton, Alberta
27 July 1979
Mr. Doug Harrington, Director
Mr. Bruce Patterson, Reclamation Specialist

(5) Saskatchewan Dept. of Environment
Hydrology Branch
Regina, Saskatchewan
Mr. Ray Pentland
Mr. Alex Banga

Aase, J.K. and Siddoway, F.H. 1976. Influence of tall wheatgrass wind barriers on soil drying. Agron. J., Vol. 68, pp. 627-31.

Abstract

Virtually no direct measurements have been made to determine if wind barriers, in fact, do affect evaporation from bare soils. Our objective, therefore, was to quantify the effect of tall wheatgrass (Agropyron elongatum) wind barrier system on soil drying from fallow soil compared with open-field fallow. The experiment was done on a Williams loam soil (fine-loamy, mixed, frigid family of Typic Agriborolls) near Sidney, Mont. We applied a 3.8 cm irrigation and sampled for soil water content at half-hour intervals and small depths increments to 10 cm. Ancillary data collected included wind in the barrier interval and in the open, plus global radiation, air temperature, and humidity in the open. The north-south oriented system consisted of 8 double-row tall wheatgrass barriers 1.2 m tall, 183 m long, with seven 15 m wide cropping intervals. For the study, we selected three locations in the third interval from the east, along with a location on an unprotected (check) area outside the influence of the barriers. The surface 4 cm of soil inside the barrier system remained wetter for about 3 days after the irrigation as compared with the check area. The drying rate remained constant at all four locations until approximately noon the day after irrigation. Thereafter, drying rate was influenced by exposure to wind. There are many periods of small, intermittent precipitation events during April and May when tall wheatgrass barriers could benefit a crop by creating a suitable soil water environment for seed germination, plant emergence and establishment, and soil resistance to wind erosion.

Aase, J.K., Siddoway, F.H. and Black, A.L. 1976. Perennial grass barriers for wind erosion control, snow management and crop production. In Shelterbelts on the Great Plains, Great Plains Agr. Council Publ. No. 78, Denver, Colo. pp. 69-76.

Abstract

Wind in a perennial tall wheatgrass (Agropyron elongatum) barrier system seldom exceeds the threshold velocity for wind erosion. The increased, relatively uniform field distribution of snow trapped by the barriers has consistently resulted in higher overwinter soil water recharge with a barrier system as compared with exposed fields. Wheat, particularly during average or below-average rainfall years, benefits from barrier protection and yields higher than wheat on exposed fields.

Aase, J.K. and Siddoway, F.H. 1974. Tall wheatgrass barriers and winter wheat response. Agric. Meteorol., Vol. 13, pp. 321-328.

Abstract

Effects of tall wheatgrass (Agropyron elongatum) barriers on microclimate and development of winter wheat (Triticum aestivum) were investigated on a dryland farm near Culbertson, Montana, U.S.A. Growth and development of winter wheat benefited more from the barriers during a year of average rainfall than during a year of above-average rainfall. Influence of the barriers on air temperatures was not consistent. Early-season soil temperatures were higher near the barriers than in the check area. Wind reduction, during the early part of the season when protection is most essential, was substantial.

Anderson, D.T. 1961. Surface trash conservation with tillage machines. Can. J. Soil Sci., Vol. 41, pp. 99-114

Abstract

The conservation or reduction of surface trash resulting from the use of some common tillage implements for cultivating fallow land has been studied in a series of 32 field trials. The weight of the surface trash cover was determined before the first tillage stroke was conducted and again after each operation. The data for each trial were collected over a fallow period of about 2 months and were expressed as a percentage of the original weight of the spring wheat stubble cover.

The wide-blade cultivator reduced the original surface cover by generalized values of 15, 10 and 5 per cent or less after the first, second, and third and subsequent operations, respectively. Results with the rod weeder, when used for secondary tillage, were similar to those given above for the wide-blade cultivator. These machines, if used for two operations on fields initially tilled with the one-way disk, lifted an average of 14 and 11 per cent of the original cover back to the surface.

The heavy-duty cultivator reduced the original surface cover by average values of 30 to 50 per cent during primary tillage and 5 to 20 per cent during the second operation. These results were strongly influenced by factors involved in machine operation.

Generally, the one-way disk and the one-way flexible-disk-harrow (discer) reduced surface cover by 50 per cent during each operation at a depth of 3 to 4 inches. Trash reduction during primary tillage with the one-way disk increased with an increased depth of tillage and decreased with increased weights of surface cover. The tandem disk provided about the same results as the other disk machines.

The use of one or more machines in a tillage sequence provides a means of regulating surface trash on a quantitative basis.

Anderson, C.H. 1971. Comparison of tillage and chemical summerfallow in a semiarid region. Can. J. of Soil Sci., Vol. 51 (3), pp. 397-403.

Abstract

Chemcial treatments using contact and systemic herbicides were compared with cultivation for summerfallow preparation on a Wood Mountain clay loam soil from 1964 to 1969, inclusive. Use of chemical alone was equal to cultivation in its effect on soil moisture conservation, soil temperature and yield of wheat. Summerfallow prepared by chemical only conserved 62% of the original crop residue, compared with 35% for normal cultivated fallows. Chemically prepared fallows were less erodible (fewer soil particles < 1 mm in diameter) at the completion of tillage in the autumn than cultivated fallows. However, the chemically fallowed soils exhibited the least aggregation over winter and were slightly more erodible by spring than the cultivated soils. The general trend was for lower NO_3^--N values in the fall and prior to seeding in the spring for wholly chemical than for wholly cultivated summerfallow, but the differences were not usually significant.

Arnold, K.C. 1961. An investigation into methods of accelerating the melting of ice and snow by artificial dusting. In Geology of the Arctic, pp. 989-1013.

Abstract

During the sumer of 1959 the author conducted experiments on snow, sea ice, and lake ice in an attempt to accelerate their rate of melting by artificial dusting. Seven different types of materials were used, differing in particle size and in the presence or absence of salt or sand. Each of these materials was spread in amounts of 100, 300, 500, 700, and 1000 grams on squares one square metre in area. This gave thirty-five squares to study on each of the snow, sea ice, and lake ice surfaces.

During the summer, repeated measurements were taken in each of these squares, using a level and rod to measure the departure of each square from a system of reference stakes. A comparison was also made with untreated areas, which served as a control. Cores and stereoscopic photographs were taken in each square of the sea and lake ice surfaces, illustrating the penetration of the dust into the ice surface. Meteorological readings are available at three-hour intervals in the areas studied.

The results are discussed and some comparisons made between the different surfaces and materials. Former practical applications of this method are referred to, and possible future applications are suggested.

Bakaav, N. 1970. Banded cover crops for fallow in Northern Kazakstan. Zemledeliye, Vol. 10, pp. 19-21.

Abstract

Agriculturalists in Norther Kazakstan are well aware of the benefits of clean fallow and have around 20% of the cultivated land under fallow. However, clean fallow is not used sufficiently to date. In the winter there is a serious loss of water due to drifting and in spring runoff in a major problem. The job of the agriculturalist is to improve collection and storage of winter precipitation. Snow ridging has been performed but it is almost impossible on fallow land due to lack of snow cover. Snow ridging can be done only when the snow is held by cover crops. The best cover crop is mustard since it is fast growing and it protects the soil and suppresses weeds. The mustard is seeded in bands 12 m apart between the 10th-20th of July. To get better weed control it is advised to seed 9-11 rows of mustard and at each cultivation 1 row of mustard is removed from each side. This leaves 4-6 rows for winter which is the optimum amount of rows for effective snow trapping. At the end of September the pitting one way disc (some discs off centre) is used to cultivate between bands. As a result the bands of mustard hold the snow and the pits catch the melted snow water to allow good moisture penetration. After the snow is gone and the land is dried harrowing is done to seal the moisture in and to level the land. At the Grains Institute in 1968-1969 bands of mustard reached a height of 70-100 cm conserving 40-55 mm of productive moisture and raising yields 3 quintals/hectare.

Bauder, J.W., Brun, L.J. and T.H. Krueger. 1975. The relationship of f soil freezing to snowmelt runoff. North Dakota Farm Res., Vol. 32 (6), pp. 10-13.

Abstract

Surface runoff of spring snowmelt and early season precipitation from frozen ground may contribute significantly to high stream levels and water quality degradation. Studies are being initiated to evaluate the impact of agricultural management practices associated with irrigation or soil frost formation and surface runoff of snowmelt.

Black, A.L. and Siddoway, F.H. 1975. Snow trapping and crop management with tall wheatgrass barriers in Montana. In Snow Management on the Great Plains, Great Plains Agr. Council Pub. No. 73, Lincoln, Nebraska. pp. 128-136.

Abstract

Conserving soil water and controlling wind erosion continue to be prerequisites for stabilizing crop production on dryland in the semiarid Great Plains. Summer fallow has been the foundation of soil water conservation in the semiarid Great Plains. Stubble-mulch fallow and strip-cropping have been the foundation for erosion control.

Even though present-day equipment, timely operations, and mulching techniques have improved storage of precipitation in fallow soils, 60 to 80 percent still evaporates, runs off, or percolates below the root zone. Percolation is now causing extensive salinization of previously productive dryland soils through the development of saline seeps in the northern Great Plains. Thus, a farming system other than crop-fallow is needed. The advantages and disadvantages of summer fallow in the northern Great Plains have recently been documented, and the need for more intensive and more flexible cropping systems to use available water supplies more efficiently has been recognized. In shifting from conventional crop-fallow to more intensive cropping, there will be a corresponding shift from a system with frequently too much water for storage under fallow to a system with frequently too little water for economic annual crop production. However, intensive cropping systems involving limited use of fallow may be considerably more feasible than previously believed, because of the continued advancement of new technologies such as minimum tillage, snow management, crop residue manipulations, and improved crop varieties.

The tall wheatgrass barrier system of conservation farming has shown promise for increasing soil water supplies through snow trapping, with the added bonus of controlling wind erosion. Utilizing additional water provided by the barrier system will require the best known soil management practices regarding fertilization, tillage, seedbed preparation, weed control, and cropping sequences. Since 1968, we have been investigating these soil management factors as a means of efficiently utilizing the additionalwater conserved. This article summarizes results of 7 years of cropping and soil management research in relation to intensive farming practices within the grass barrier system.

Berndt, H.W. 1964. Inducing snow accumulation on Mountain Grassland Watersheds. J. Soil and Water Cons., Vol. 19, pp. 196-197.

Abstract

The entire surface of each snow particle is exposed during drifting and it is likely that significant amounts of moisture are lost to the atmosphere through evaporation or sublimation. Such losses could be reduced by retaining snow where it falls and accumulating it in drifts to reduce the area of snow surface exposed to drying winds. Limiting snow movement on high windswept plains may increase water yields. The windbreak action of vegetative barriers can cause local snow accumulation but much of the West lacks sufficient natural wind barriers to limit drifting and provide storage for the amount of snow received.

Black, A.L. 1970. Soil water and soil temperature influences on dryland winter wheat. Agron. J., Vol. 62, pp. 797-801.

Abstract

Effects of wheat straw mulch on soil water and soil temperature in the 0- to 7.6-cm soil layer and their subsequent influence of plant development and grain yields of winter wheat (Triticsum aestivum L., 'Winalta') were evaluated over a 3-year period. Mulch rates of 0, 1,680, and 3,360-kg/ha were applied randomly or in bands centered over or between wheat rows planted in 35-, 70-, and 90-cm row spacings. Band applications of straw were applied at the same rates per unit area as that covered by randomly applied straw but in band widths of 18, 35, and 45 cm for the respective row spacings.

In a time sequence of correlations, number of tillers and number of adventitious roots were positively correlated with a moist soil-degree day index (P = .01) based on May soil water and soil temperature measurements, number of adventitious roots was postively correlated with number of heads/ha (P = .01), and number of heads/ha was positively correlated with grain yield (P = .01). Numbers of adventitious roots, tillers, and heads and final grain yields were dependent upon the soil water and soil temperature of the 0- to 7.6 cm soil layer during May. The intermediate straw mulch rate (1,680 kg/ha) applied randomly or in bands over the wheat row significantly increased the number of moist soil-degree days and grain yields in 2 or 3 years compared to bare fallow or the high straw mulch rate (3,360 kg/ha).

Black, A.L. and Siddoway, F.H. 1976. Dryland cropping sequences within a tall wheatgrass barrier system. J. Soil and Water Cons., Vol. 31, pp. 101-105.

Abstract

For 8 years we studied a system of tall wheatgrass (Agropyron elongatum 'Alkar') barriers designed to control wind erosion and to collect and hold snow overwinter to determine if increased soil water recharge can support more intensive cropping than crop-fallow rotations. The barriers nearly doubled overwinter soil water storage the first 9 months compared with unprotected land. With nitrogen and phosphorus fertilization, average annual grain yields were 30 to 69 percent higher for intensive cropping systems than for conventional spring wheat-fallow. Continuous cropping systems used 71 to 80 percent of the average precipitation received between crop harvests, whereas spring wheat-fallow used 30 percent. Therefore, the amount of water unaccounted for between crops, some of which may contribute to saline seeps, averaged 21.8 inches for spring wheat-fallow and 3.1 to 4.5 inches for continuous cropping. In addition to controlling wind erosion, the grass barrier system provided the additional soil water needed, without fallow, to make intensive cropping feasible.

Black, A.L. and Siddoway, F.H. 1971. Tall wheatgrass barriers for soil erosion control and water conservation. J. Soil and Water Cons., Vol. 26 (3), pp. 107-111.

Abstract

A perennial grass barrier system of conservation farming was evaluated for soil-water conservation and soil erosion control. Each barrier consisted of two rows of tall wheatgrass (Agropyron elongatum) seeded in 36-inch rows. Barriers were spaced 30 or 60 feet apart. By trapping snow, the continuous crop sequence with barriers stored 86 to 116 percent as much water as crop-fallow without barriers. At a height of 12 inches, windspeed from leeward of one barrier to windward of the next barrier increased from 17 to 70 percent of open field windspeed in the 30-foot barrier spacing and from 19 to 84 percent in the 60-foot interval.

Bole, J.B. and U.J. Pittman, 1978. The effect of fertilizer N, spring moisture and rainfall on the yield and protein content of barley in Alberta. Proc. of the 1978 Soils and Crop Workshop Publ. No. 390, Saskatoon, Sask. pp. 114-122.

Abstract

This study took place at the Lethbridge Research Station which is in the Dark Brown Soil Zone. It receives an average of 400 mm annual precipitation with about 1/3 of this falling in the summer. Recropping is becoming more popular due to use of N fertilizers, better chemical weed control and better moisture conservation. Wind erosion and dryland salinity due to unnecessary summerfallowing have encouraged recropping. Barley yield was highly dependent on available soil water. One cm of soil water moisture increased barley yield by 160 to 230 kg/ha at the 5 cm level and from 0 to 80 kg/ha at the 20 cm level. Therefore any technique which can control the erosion and runoff of winter precipitation can increase available soil water and hence, increase crop yields. This makes the idea of recropping an economical and a conservational asset to any farmer. If the producer wishes recropping to be profitable 6 years out of 10, more than 10 cm of soil water must be present on June 1 before recropping should be practiced.

Bond, J.J., Power, J.F. and Willis, W.O. 1971. Soil water extraction by N-fertilized spring wheat. Agron. J., Vol. 63, pp. 280-283.

Abstract

Field experiments were conducted to determine the effect of applied N on water use by continuously cropped spring wheat. Applied N increased vegetative growth and soil water extraction prior to heading. In two of the three sample years, this extraction of the soil water reserve resulted in less soil water extraction after heading by the N-fertilized crop than by the nonfertilized crop. Applied N did not increase depth of soil water extraction. Overwinter recharge of soil water was inversely related to soil water content at harvest.

Bond, J.J., Power, J.F. and Willis, W.O. 1971. Tillage and crop residue management during seedbed preparation for continuous spring wheat. Agron. J., Vol. 63, pp. 789-793.

Abstract

Field experiments were conducted to determine the effect of four tillage and crop residue management methods of seedbed preparation on continuous spring wheat (Triticum aestivum L.) receiving four rates of applied N. Effects of tillage and surface-crop residues were separated by seedbed treatments of (a) conventional moldboard tillage, (b) conventional stubble mulch tillage, (c) moldboard tillage with part of the surface residue removed before and replaced after tillage, and (d) moldboard tillage with all surface residue removed before and replaced after tillage. Treatments were evaluated relative to grain yields, yield components, dry-matter production, N uptake, soil nitrate content, soil temperature, plant water use and weed populations. For 3 to 4 years average grain yields (for all N rates) were 1,380, 1,060, 1,380, and 1,330 kg/ha for treatments a, b, c, and d, respectively. Yield reduction with stubble mulch tillage was related to poor weed control (primarily green foxtail) and not to the effects of surface residue per se. Use of fertilizer N failed to overcome yield reduction associated with stubble mulch tillage.

Bowren, K.E. 1971. Effect of fall and spring treatment of stubble land and yield of wheat in the Black soil region of Manitoba and Saskatchewan. Canadian Agric. Engineer, Vol. 13 (1), pp. 32-35.

Abstract

In the park belt region of the prairie provinces the need for fall tillage of stubble land which is to be seeded the next spring has been questioned on numerous occasions. The removal of trash by burning combine straw, a practice condemned by conservationists has been practiced consistently on many farms in the area. Several different types of machines are used with success for fall tillage. Tillage with these machines reduces the combine trash on the soil surface facilitating trash clearance with seeding equipment. Fall tillage has also been recommended for the control of annual and perennial weeds. By working the land, crop and weed seeds are encouraged to germinate and be killed by winter freezing or preseeding tillage in the spring. Trash cover reduces erosion and improves the physical and chemical properties of the soil.

Branson, F.A., Miller, R.F. and McQueen, I.S. 1966. Contour furrowing, pitting, and ripping on rangelands of the Western United States. J. Range Management, Vol. 19, pp. 182-190.

Abstract

The effects of mechanical treatments, such as contour furrowing, pitting, and ripping, on forage production and water storage were measured in Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. Of seven kinds of mechanical treatment evaluated, contour furrowing at 3- to 5-foot intervals and broadbase furrowing were most effective. The greatest beneficial responses occurred on medium- to fine-textured soils. Measurements at 20 locations including 8 types of vegetation receiving a single kind of treatment, contour furrowing, revealed that Nuttall saltbush responds most favorably to the treatment. Winterfat, black grama, and needleandthread provided unfavorable sites for mechanical treatments.

Branson, F.A., Miller, R.F. and McQueen, I.S. 1962. Effects of contour furrowing, grazing intensities, and soils on infiltration rates, soil moisture and vegetation near Fort Peck, Montana. J. Range Management, Vol. 15, pp. 151-158.

Abstract

Thousands of acres of low-producing range lands in the Western United States were contour furrowed during and after the 1930's in an effort to improve moisture utilization. There have been various reports on the effectiveness of furrowing. An early report indicated that there were noticeable increases in plant growth due to increased soil moisture storage. A study in Arizona reported that contour furrows retained their effectiveness at the end of ten years and recommended studies of contour furrowing as a preparation for reseeding. Furrows spaced at five-foot intervals significantly increased forage production in southeastern Wyoming but wider spacings were not effective. Furrows were of no value in Canada since they became filled with ice and snow. Results in New Mexico show that furrowing did not increase plant production on sandy soils.

Connaughton, C.A. 1935. The accumulation and rate of melting of snow as influenced by vegetation. J. Forestry, Vol. 33, pp. 564-569.

Abstract

Seventy-five percent of usable streamflow originates from winter precipitation. Therefore, it is important to modify vegetative cover in order to enhance or impair the accumulation or melting of snow. The retardation of the rate of melting of snow by a forest cover is one valuable means of increasing duration of run-off and distributing the peak flow of rivers and streams over a considerable period of time. A brush cover, while very effective in accumulating snow, is of little value in retarding the rate of melting and aiding in distributing the peak streamflow.

Curtis, W.R. 1971. Terraces reduce runoff and erosion on surface-wind benches. J. Soil and Water Cons. Vol. 26, pp. 198-199.

Abstract

A two-year study in Breathitt Country, Kentucky, indicated that terraces can effectively control runoff and erosion on surface-mine benches. In an area where the spoil was predominantly shale, peak flows on a terraced plot averaged 65 percent less than on the control plot, sediment yield averaged 52 percent less, and total runoff averaged 42 percent less. Comparable figures on a set of plots having substantial amounts of sandstone were 65, 70, and 6 percent, respectively. Average storm runoff duration was 1 percent higher on the terraced plot of each pair.

Dawley, W.K., Dryden, R.D., McCurdy, E.V., Molberg, E.S., Bowren, K.E. and Dew, D.A. 1963. The effect of cultural and fertilizer treatments on yields of wheat on second crop land. Can. J. Soil Sci., Vol. 44, pp. 212-214.

Abstract

Trash cover protects soil from erosion, improves soil structure, increases moisture retention, and reduces soil temperature in semi-arid regions. These facts and their importance have been generally recognized and accepted on the prairies. However, large quantities of stubble and straw (combine residue) which remain following the harvest of cereal crops in years of favorable production create problems in preparing land for reseeding. The problems are varied but may be categorized as follows: (1) cultural, involving the techniques of good farm practices to protect the soil and maintain its physical structure; (2) mechanical, involving the management of trash by tillage machines; (3) production, involving the effect of light, heavy, and excessive amounts of residue on subsequent grain yields.

Proper management of trash cover can be important in minimizing problems in seedbed preparation. The amount of trash can be regulated quantitively by the proper choice of machines for tillage operations. Low yield on stubble land resulting from excess removal of plant nutrients by the preceding crop can be counteracted by proper fertilizer practices. When low yields result from the presence of large quantities of undecomposed organic matter, the initial decay of crop residue can be accelerated by applications.

de Jong, E. and Rennie, D.A. 1969. Effect of soil profile type and fertilizer on moisture use by wheat grown on fallow or stubble land. Can. J. Soil Sci., Vol. 49, pp. 189-197.

Abstract

Equations describing yield as a function of moisture use are reported for fallow-seeded wheat for the years 1960 to 1965, inclusive, and for wheat seeded on stubble land from 1964 to 1967. In general, yields increased linearly with water use; second-degree functions did not greatly increase the correlation, but represent more realistic yield functions. The increase in yield per cm water used was larger on fallow than on stubble land, and increased with fertilization. Growing season precipitation ranged from 5 to 26 cm during the study period; the long-term average is 19 cm. Mean yields for unfertilized and fertilized fallow and stubble wheat were 1,500 and 1,860 kg/ha, and 1,340 and 1,720 kg/ha, respectively.

Yield, water used, and water use efficiency varied somewhat, depending on whether the crop was grown on a knoll, upper slope, lower slope, or in depressional areas.

de Jong, E. and Steppuhn, H. An editor. Water conservation practices on the Canadian Prairies. Dryland Agriculture Monograph, American Society of Agronomy and Soil Science, Chapter 2, Water Conservation.

Abstract

About 1/3 of the fall and winter precipitation is stored on stubble fields, but on fallow fields only about 1/10 is stored. The main factors determining the recharge efficiency of the snow are the amount of snow retained on the area and the run-off losses of meltwater. Runoff from snowmelt depends on the rate of thawing of the snowpack and the infiltration rate of the soil. 60% of the snowcover on fallow fields flows overland as run-off compared to 25% or less on stubble fields. Snow is suitable for management because of: 1) its availability for manipulation while stored aboveground, 2) its susceptibility to redistribution by wind, and 3) its compatability with existing cropping practices. Some snow management techniques include 1) stubble management, 2) snowplowing and 3) vegetative barriers. These methods of snow harvesting could increase overwinter soil water recharge by 5 cm.

Diebert, E.J. 1979. No-till influence on soil temp, moisture and campaction. Proc. Zero Tillage Workshop, Brandon, Manitoba, University of Brandon, Extension Division.

Abstract

In warmer climates the winter soil temperatures for no-tilled land are considerably cooler than cultivated land. In cooler climates the winter soil temperature is higher for no till farming due to the early snow trap which creates an insulating effect. The overwinter soil moisture loss is considerably lower for no tilled land than fallow land. Therefore, during a dry spring season the losses may make the difference between good and poor plant emergence. No till farming also increases the water storage efficiency of the soil. The storage efficiency of the bare fallow exposed over the winter was 17 percent while the efficiency of the stubble was 50 percent. This low efficiency of the fallow plus the high evaporation during fallow season emphasizes the inefficiency of the alternate crop-fallow system

Doering, E.J. and Reeve, R.C. 1965. Engineering Aspects of the reclamation of sodic soils with high-salt waters. J. Irrigation and Drainage Div., Proc. of the ASCE. pp. 59-72.

Abstract

For sodic soils to be reclaimed by leaching, two conditions must be satisfied: 1) the leaching water must be relatively high in calcium and magnesium ions; and (2) the water must percolate through the soil profile so calcium and magnesium can be exchanged with sodium. Since sodic soils tend to disperse when treated with low-electrolyte water the infiltration rates are so low that reclamation is impractical. High-salt waters act as flocculants and favorable infiltration rates prevail even with highly sodic soils.

Doty, Robert D. 1970. Influence of contour trenching on snow accumulation. J. Soil and Water Cons., Vol. 25, pp. 102-104.

Abstract

Contour trenches for watershed rehabilitation in Utah were evaluated with regard to their effect on snow accumulation. The trenches studied are on a windswept southwest exposure where snow redistribution by wind is important. Trenches increased snow accumulation slightly, which appeared to be more significant to revegetation than to water yield.

Dyck, G.D., Del Erickson and H. Steppuhn. 1979. Snow ridging to increase soil water. Proceed. of the 1979 Soils and Crops Workshop, Extension Division, University of Saskatchewan, Saskatoon, Saskatchewan Soil Management 510, Publ. No. 403 pp. 1-12.

Abstract

The following observations were made from the testing of snow ridging

1) The ridging of snow in fields which were fallowed the previous summer has been proved difficult and uneconomical.

2) The establishment of satisfactory ridges generally requires two plowing operations, one as early as permanent winter snowcover materializes (December and another in January or early February.)

3) Functional ridges spaced 12 feet (3.7 m) apart were obtained with front-mounted V or straight black plows, 8-foot wide. The average operational cost of one ridge plowing amounts to less than one cultivation in a summerfallow operation.

4) No advantage in snow trapping efficiency could be detected for directional orientation of the ridges.

5) To avoid scouring of the seedbed; the plow blade was raised 1-2 inches (3-5 cm) above the soil surface.

6) Soil and crop residue incorporated with the ridge-forming snow exhanced energy absorption from radiation. Consequently, the ridged snow melted earlier and quicker than the cleaner snow deposited between the ridges.

7) Following ridging the relatively bare inter-ridged soil are subject to considerable heat loss, becoming quite cold if not covered by fresh snow; later these zones take longer to thaw, reducing their infiltration capacity for the melted snow.

8) Snow ridging is cold miserable work as the optimum ridging is generally required just after a major snowfall when air temperatures are often lowest.

Dyunin, A.K. 1966. Fundamentals of the mechanics of snow storms. Proceed. Int. Conf. on Low Temperature Sciences, Sapporo, Japan, Vol. 1, Part 2, pp. 1065-1073.

Abstract

Snow storms or blizzards are regarded as a two-phase turbulent streams with hard particles, arising on the interface of wind streams and snow cover. The magnitude of the solid flux is not constant when it reaches maximum. It suffers rather regular vibrations subsequently which are explained by the changeable drawing pressure within the thin boundary layer. The author is of the opinion that this principal fact explains the origin of the characteristics forms of free snow cover relief.

In contrast to sand storms and soil erosion, in a snow stream marked phase transitions occur owing to flake evaporation. Numerous tests showed that snow evaporation took place at a more intensity during snow storms as compared that in the absence of the snow transfer, which may partly be explained by the exposure of all surfaces of flakes in a snow stream.

A theory of analytical calculation of wind and snow protection barrier action which is substantiated by numerous laboratorial and field data was developed.

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Dyunin, A.K. 1961. Vertical distribution of solid flux in a snow-wind flow. National Res. Council Tech Trans. 999. From Trudy Transportno - Energeticheskogo Instituta, Vol 4, pp. 49-58.

Abstract

In this paper an attempt is made to analyze theoretically the distribution with height of the solid flux in a snow-wind flow. The analytical results are compared with field observations.

Dyunin, A.K. 1963. Solid flux of snow-bearing air flow. National Research Council Tech. Translation 1102. From Trudy Transportno - Energeticheskoga Instituta, Vol. 4, pp. 111-118.

Abstract

In this paper a general formula is derived, using dimensional analysis, for the solid flux of a "fluid + granular material" mixture and is applied to the particular case of snow-bearing air flow.

For practical purposes of combatting snow and designing new roads in regions subject to snowdrifting one requires precise knowledge of the laws governing snow transfer. It is particularly important to know the factors governing the solid flux of a snow-bearing air flow.

Dyunin, A.K. 1963. The mechanical conditions of snow erosion. National Res. Council Tech. Translation 1101. From Trudy Transportno - Energeticheskogo Instituta Vol. 4, pp. 59-64.

Abstract

Snowdrifts can be a major source of disruption in the operation of transportation services and a general nuisance in the normal wintertime activity of a community. Such drifts are formed whenever a wind, strong enough to transport horizontally a significant amount of snow, encounters an obstacle which forces it to deposit some of this snow. The usual approach taken in defending an area or structure against snowdrifting has been to locate the structure properly so that the drift problem will be minimum and to erect obstacles, such as snow fences, to control where the snow will be deposited. The approach taken in the development of these defences has been largely empirical. Attention has been directed primarily to the character of the air flow with little attention being given to the material transported. In some circumstances, it would be an advantage to have a more complete defence against snowdrifting than is now available. In their attempts to develop this defence, engineers are giving more consideration to the theoretical aspects of the problem and in particular to the relationships between the air flow and the snow being transported.

Faulk, Duane E. 1975. Summerfallow, is there a better way to store water. Crops and Soils, Vol 28 (3), pp. 9-11.

Abstract

One disadvantage using fallow to store water is that more moisture is absorbed than is needed by the crop, and the additional moisture moves elsewhere often causing problems such as saline seeps. Tests have shown that each inch of water above 8 inches will produce about 6 to 7 bushels of grains. About 50% of summer precipitation is lost by evaporation and the remainder percolates too deeply into the soil for the roots to reach, therefore summerfallow is quite inefficient. If summerfallowing is going to be reduced, then snow management techniques are needed to utilize winter precipitation. With winter wheat, additional snow has many advantages. The soil will have twice as much water as a cultivated field that was bare of snow and there will be less winterkill and frost heaving due to the insulating value of the snow. Effective barriers for snow management include 1) stubble, 2) tree windbreak 3) perennial wheatgrass barrier. If snow management techniques are used properly this could result in annual re-cropping. Annual cropping stores only enough moisture for one year's crop and thus eliminates the recharge of saline seep areas.

Farmer, E.E., Brown, R.W., Richardson, B.Z. and Packer, P.E. 1974. Revegetation research on the Decker Coal Mine in southeastern Montana. USDA Forest Service Res. Paper INT-162. 12 pp.

Abstract

First-year results of revegetation research at the Decker coal mine in southeastern Montana are described. Three types of main plots were located on overburden material: (1) a control plot, (2) an irrigated plot, and (3) a plot dressed with topsoil materials. Each main plot consists of 48 subplots for a total of 144 subplots. Treatments included different grass mixtures, fertilizer, and mulch on irrigated and unirrigated plots. On the basis of dry-weight grass production, several treatments produced acceptable first-year grass stands. The top-dressing of mine overburden appears to be a highly desirable revegetation practice. Generally, wheatgrasses (Agropyron spp.) have dominated the dry-weight production.

Frank, A.B. and George, E.J. 1975. Windbreaks for snow management in North Dakota. In Snow Management on the Great Plains. Great Plains Agr. Council Publ. No. 73, Lincoln, Nebraska. pp. 144-153.

Abstract

Originally, field windbreaks were established to prevent wind erosion, As tree planting became more popular other aspects such as increased crop production, and increased wildlife habitat were additional reasons for planting windbreaks. To best manage snow in field windbreaks, the objective should be to trap snow over as a wide cropping area as possible. The most popular windbreak is the Siberian elm which has a high winter density and is most often planted at 3 to 4 ft. spacings. Pruning and thinning windbreaks are a temporary measure to control snowpack accumulation. Pruning opens up the area beneath the tree allowing less snow to be trapped in the immediate area of the windbreak. Pruning does have its disadvantages - it is labourious and it encourages weed infestation which creates a dense understory similar to unpruned trees.

Frank, A.B., Harris D.G. and Willis, W.O. 1974. Windbreak influence on water relations, growth and yield of soybeans. Crop Sci., Vol. 14, pp. 761-765.

Abstract

Response to 'Norman' soybeans (Glycine max (L.) Merr.) to a shelter-induced microclimate was studied under dryland and irrigated soil water regimes. Leaf water potential (Ψ_l), xylem water potential (Ψ_x) stomatal diffusion resistance (r_s), canopy temperature, dry matter accumulation, leaf area, leaf density, plant height, and yield components were measured to determine the effects of shelter influences on a soybean crop.

Plant water status, characterized by measuring Ψ_l, Ψ_x, Ψ_s, r_s, and canopy temperature during selected days, was strongly affected by soil water regime and sheltered conditions. The treatment combination of shelter plus irrigation resulted in the most favorable plant water status. Under dryland, where soil water was limiting, plant water status of the sheltered and exposed treatments was similar.

Dry matter production, green leaf area, and plant height were generally increased under sheltered treatments if soil water was not limiting. Dryland sheltered treatments showed early vegetative stimulation when compared to exposed treatments, but the resulting depletion of soil water in the sheltered treatment restricted later growth. Both irrigated and dryland sheltered plants had a lower leaf density compared to exposed plants.

Soybean yields were increased from 20.4 hl/ha for the irrigated exposed treatment to 24.0 hl/ha for the irrigated sheltered treatment. Under dryland, the yields were 11.8 and 12.8 hl/ha for exposed and sheltered treatments, respectively.

Frank, A.B. and Willis, W.O. 1972. Influence of windbreaks on leaf water in spring wheat. Crop Sci., Vol. 12, pp. 668-672.

Abstract

Spring wheat (Triticum aestivum L.) was grown for 2 years with three shelter conditions: (a) exposed, (b) surrounded by a slat barrier, and (c) adjacent to tree shelterbelts. Leaf water potential, stomatal diffusion resistance, and meteorological factors were monitored on selected days. The shelterbelt and slat-barrier plots received 28 and 69% as much wind as the exposed plot, respectively. Air temperature was slightly higher in the sheltered plots. Vapor pressure deficits were similar for all three conditions. Generally, leaf water potential was consistently lower in the exposed compared to the sheltered plots. The more favorable leaf water potentials were associated with those plots receiving less total wind movement. Stomatal diffusion resistance was less and at a lower leaf water potential for exposed compared to sheltered plants. The data indicate that water relations of wheat plants are more favorable for plant growth and yield when grown with shelter compared to exposed conditions.

Frank, A.B., Harris, D.G. and Willis, W.O. 1977. Growth and yield of spring wheat as influenced by shelter and soil water. Agron. J., Vol. 69, pp. 903-906.

Abstract

In the Northern Great Plains, windbreaks have historically been used to protect crops and soils from winds, but data on the effects of windbreaks on growth and yield of small grains is limited. "Waldron' wheat (Triticum aestivum L.) was grown on Parshall fine sandy loam (Pachic Haploboroll) with and without shelter (slat-fence enclosures), both with and without irrigation, to determine the effects of soil water and shelter on wheat growth and yield. In 1973 and 1974, plant height, tiller production, leaf area index (LAI), specific leaf weight (SLW), and dry matter were measured at tillering, heading, and grain-filling growth stages. Also, grain yield, kernel weight, number of heads, straw yield, and plant height were measured at crop maturity. The combination of shelter and irrigation resulted in greater dry matter production, higher LAI, lower SLW, more tillers per plant and taller plants than irrigation alone. Shelter for dryland (nonirrigated) wheat did not increase vegetative growth, other than plant height early in the growing season. With irrigation, sheltered wheat yields increased 6.4 q/ha or 21.8% over the exposed wheat. Dryland sheltered wheat yield was 3.8 q/ha or 19.4% less than that for the exposed crop. Number of heads and straw production for each treatment treatment responded the same to soil water and shelter as did grain yield. Results of this study show that growth and yield of spring wheat in the Northern Great Plains is increased significantly when grown under sheltered vs. exposed conditions provided soil water supply is adequate.

Frank, A.B., Harris, D.G., and Willis, W.O. Influence of windbreaks on crop performance and snow management in North Dakota. In Richard W. Tinus (ed). Proceedings of the Symposium: Shelterbelts on the Great Plains. Great Plains Agricultural Council Publication No. 78, pp. 41-48.

Abstract

Effects of windbreaks on plant water relations, plant growth, crop yields, and snow management were investigated. Results showed that, if soil water is not limiting, plants growing adjacent to noncompetitive windbreaks had a more favorable plant water status than plants not protected by windbreaks. With limited soil water, windbreaks may contribute to increased plant water stress. Growth and yield of spring wheat (Triticum aestivum L.) and soybeans (Glycine max (L.) Merr.) were increased significantly when grown with a combination of shelter and irrigation, but under dryland, shelter did not increase crop yield. Winter effects of windbreaks contribute to yield increases of spring wheat more than do summer effects, and winter and summer effects are additive during dry years in determining yields of a crop protected by a permanent windbreak. Snow trapping by single-row field windbreaks often creates a large, narrow snowdrift adjacent to the tree row, but snowdrift shape can be altered by thinning and pruning of windbreaks. Such alteration can benefit a larger crop area and simultaneously reduce the potential for water erosion resulting from snowmelt water or large snowdrifts.

George, E.J. 1970. Tree windbreaks and slat barriers. U.S. Dept. of Agriculture, Prod. Report No. 121, 23 p.

Abstract

Tall trees reduced wind velocity on their leeward side for greater distances than did shorter shrubs. Effective wind reduction of 40 percent extended to 10 H. Series of one-row tree windbreaks at intervals of 20-40 rods gave little evidence of cumulative reduction in wind velocity or in trapping snow. Slat barriers reduced wind velocity at comparable locations approximately the same amount regardless of wind direction. Removal of lower branches from trees in dense windbreaks to 5 feet above ground gave a much wider snow distribution of less depth on the side of trees pruned to 4.5 feet. Removal of every other tree in closely planted windbreak rows shows promise of spreading snow over wider areas of cropland. Improved planting practises now being used of spacing trees and shrubs farther apart in the row will solve many of the problems confronting farmers who have high-density windbreaks.

George, E.J., Broberg, D. and Worthington, E.L. 1963. Influence of various types of field windbreaks on reducing wind velocities and depositing snow. J. Forestry, Vol. 61, pp. 345-349.

Abstract

Comparisons were made of wind velocities and snowdrift patterns on the windward and leeward sides of windbreaks and slat barriers of varying numbers of rows, designs, and densities. Density was determined by placing a dotted grid over a picture enlargement and then computing the space occupied. Windbreaks and barriers which were permeable in the lower half of the structure caused snowdrifts to form over a wider area than the less permeable ones. Such permeable structures also reduced most erosive wind velocities to a nonerosive rate. Between a series of windbreaks spaced 400 feet apart wind velocities and snowdrift deposits indicated the series had no cumulative effect on wind reduction. Proper tillage practices must still be used in conjunction with windbreaks or other structures to control wind erosion of fields.

George, E.J. 1943. Effects of cultivation and number of rows on survival and growth of trees on farm windbreaks on the northern Great Plains. J. of Forestry, Vol 41, pp. 820-828.

Abstract

Windbreaks on the northern Great Plains provide much-needed protection for men, animals, and crops against the severe storms of winter and the hot, drying winds of summer. Because of the scanty precipitation everything possible must be done to conserve the supply of moisture available for tree growth. The studies reported in this paper show that cultivation until a complete crown cover is established has a decidedly beneficial effect in this direction by reducing the competition from weeds and sod; and that relatively narrow windbreaks, of not more than 6 to 8 rows, are more effective than wider ones in storing snow in the form of drifts and thus making available a supplementary supply of water beyond that afforded by the annual precipitation.

Gerdel, R.W. and Gordon, H. Strom. 1961. Wind tunnel studies with scale model simulated snow. IASH Pub. #54. General Assb. of Helsinki. pp. 80-88.

Abstract

In Polar regions where little or no summer melting occurs, improperly designed structures may be quickly and permanently buried by drifting snow.

In most wind tunnel studies on drifting snow no consideration was given to the relationship between the velocity of air in the tunnel and the physical and aerodynamic properties of the material selected to represent snow nor to the extent of saturation of the wind with the synthetic snow.

Recognizing the deficiencies in knowledge on snow drifting and the advantages inherent in wind tunnel studies, the U.S. Army Snow Ice and Permafrost Research Establishment has supported a research program leading to the selection and use of materials which might be used to suitably simulate snow in controlled investigations on scale models of structures within the range of 1/10 to 1/50 prototype size.

Some of the results of the wind tunnel studies with a scaled, simulated snow are presented in this paper.

Greb, B.W. 1975. Problems in monitoring snowfall at Akron, Colorado. In Snow Management on the Great Plains. Great Plains Agric. Council Publ. #73. pp. 1-12.

Abstract

Since about 40% of all snowfalls at Akron involve snowdrift formations usually ranging from 12 to 48 in. deep, a new experiment was designed in the summer of 1959 to deliberately stockpile snow with parallel vegetative barriers for water conservation purposes on crop land. In 1963 and 1964 a similar experiment was initiated utilizing wood slat snow fences of various air porosities to produce snowdrifts. The leeward distance and configuration to drifts varied with wind speed and snow water content for individual storms. In each snowdrift stockpile experiment the water content of newly formed snowdrifts was measured to determine differences between drifts and an adjacent level of undisturbed snow. The average water content for the drifted snow was 19.6% compared to 12.9% for the undisturbed snow.

Greb, B.W. 1975. Snowfall characteristics and snowmelt storage at Akron. Colorado: In Snow Management on the Great Plains, Great Plains Agr. Council Pub. No. 73. Lincoln, Nebraska. pp. 45-63.

Abstract

Snowfall statistics recorded for the last 19 years at Akron, Colorado, showed an average of 11.7 snowfall events/season and 13.6 days/season of snowfall. These storms produced 32.7 in./season average snowfall, 11.9% water content, and 3.89 in. snowfall precipitation. Seasonal variations were sometimes extreme. Data are shown for size distribution and water content of snowfall events, snowfall statistics by months, fall received during frozen and nonfrozen soil periods, characteristics of snow-drift storms and extremes of snow seasons.

Snowfall is considered a valuable resource to the water economy and agricultural productivity of the area. Snowmelt water is estimated as responsible for 45% of winter wheat production in the Akron area even though snowfall precipitation accounts for only 18 and 26% of total annual precipitation as measured with an unguarded standard rain gauge and by core sampling of snow, respectively. Snowmelt storage efficiencies averaged 53% in undisturbed wheat stubble where no extra snow was transported by wind, 75 to 100+% in stubble receiving wind-transported snow (like small plots and north edges of large fields), 38% on ungrazed native grass and 66 to 70% leeward of experimental snow fences.

In addition to protection, snowdrift manipulation systems with vegetative barriers and experimental wood-slat fences showed good water conservation potential for subsequent crop production.

Greb, B.W. and Black, A.L. 1961. New strip cropping pattern saves moisture from dryland. Crops and Soils, Vol 13 (5), pp. 23.

Abstract

Snow spreading

- a natural snow fence of parallel double rows of sorghum is grown at intervals of 50 to 150 feet across a field of summerfallow.
- sorghum is drilled in June at regular seeding rates and winter wheat is seeded between the strips at its normal time in the fall.

Snow trapping

- this involves 8-12 row strips of sorghum spaced at 3:1 or 2:1 width ratios with wheat.
- stubble catches the snow blowing off of the wheat which provides moisture for next years sorghum crop.
- other snow trapping crops are stubble strips of corn, sunflower, mustard, and safflower. Sundangrass is a highly recommended practise in the semiarid steppe regions of the Soviet Union.

Greb, B.W. and Black, A.L. 1961. Effects of windbreak plantings on adjacent crops. J. Soil and Water Cons., Vol 16, pp. 223-227.

Abstracts

Field windbreaks and farm shelterbelts are multipurpose assests to Great Plains agriculture. Though advantages outweigh the disadvantages, windbreak plantings in northeastern Colorado do depress growth and yield of adjacent annual crops. They apparently have little effect on native and introduced grasses. However, competitive effects on adjacent crops vary with age and species of the windbreak planting.

Grishin, I.S. 1975. Effect of forest shelterbelts on snow distribution in the Don River Basin. Soviet Hydrology: Selected Papers, Issue No. 3, pp. 182-184.

Abstract

The Don Basin is located mainly in climate zones which range from moderately wet to semiarid where the control and utilization of snow is of great practical importance. This is particularly true of the steppe region of basin where winter precipitation is low. The most effective snow retention techniques include a forest shelterbelt combined with another windbreak device, (snow dikes; fences, etc.). To determine the protective effect of shelterbelts, a curve of the accumulation and drifting of snow in the fields as a function of the distance between shelterbelts was constructed. The effect of snow-cover on soil temperature and the overwintering of plants was also determined.

Haas, H.J. and Willis, W.O. 1971. Water storage and alfalfa production on level benches in the Northern Plains. J. Soil and Water Cons., Vol. 26 (4), pp. 151-154.

Abstract

Level benches effectively collected snow, conserved water, and increased alfalfa yields in a 5 year study. Water storage and alfalfa yields were influenced more by a bench's favorable location for snow collection than by size of the contributing area. Water storage overwinter averaged 1.4 inches on the slope and ranged from 4.8 to 9.1 inches on the benches. Alfalfa production averaged 1.50 tons/acre on the slope and ranged from 3.20 to 1.28 tons per area on the benches.

Haas, H.J. and Willis, W.O. 1968. Conservation bench terraces in North Dakota. Trans. of the Am. Soc. Agric. Eng., pp. 396-403.

Abstract

Conservation bench terracing is a land-forming system designed to conserve soil and water. Although the system has been used in other countries for several thousand years, it did not reach the Great Plains until 1955. The bench terraces increase wheat yields about 5 bushels per acre. They influenced corn yields very little, doubled alfalfa yields, and nearly doubled bromegrass yields as compared to sloping land. Soil water storage on the benches over winter was not greatly different from storage on the slope. Overall, the results indicate that conservation bench-terrace systems have a place in northern Great Plains agriculture, especially for perennial forage production.

Haas, H.J., Willis, W.O. and Boatwright, G.O. 1966. Moisture storage and spring wheat yields on level-bench terraces as influenced by contributing area cover and evaporation control. Agron. J. Vol. 58, pp. 297-299.

Abstract

Level-bench terraces on land with 5 to 9% slope increased water storage and wheat yields as shown in a study conducted from 1959 through 1962. Various types of contributing areas were used. Runoff from wheat on grass contributing areas had minor influence on moisture storage and yields on the bench. An impervious contributing area increased moisture storage on the bench by 1.3 inches and wheat yields by 4.7 bushels per acre. Deep percolation near the base of the impervious slope caused some nutrient leaching and moisture loss. Partial evaporation control (32-inch wide plastic film strips covering 90% of minor ridges on the bench) from harvest to seeding increased moisture storage by 1.4 inches and wheat yields by 3 bushels per acre.

Results indicate possible methods of conserving precipitation normally lost, particularly during the dormant or winter period. Principal advantages of level-bench terraces appear to be collecting snow, preventing runoff of snow-melt and torrential-type rains, reducing erosion, and increasing yields through moisture conservation.

Hagen, L.J., Skidmore, E.L. and Dickerson, J.D. 1972. Designing narrow strip barrier systems to control erosion. J. Soil and Water Cons., Vol. 27, pp. 269-271.

Abstract

Compared to conventional barriers, additional factors to consider in designing narrow strip barrier systems for wind erosion control include barrier capacity and trapping efficiency (TE), i.e., the percentage of soil entering a barrier strip that is retained. A prediction equation for TE, developed from wind tunnel tests, shows TE depends on barrier height, width, and windspeed. Two-row barriers provided the best combination of consistent performance and high TE per row. The wind erosion equation can be used to obtain an initial spacing for barriers with 100 percent TE, but the initial spacing must be reduced in proportion to TE to avoid excessive soil movement. If the barrier capacity is low enough so the trapped soil also reduces barrier TE, the spacing needs to be further reduced or the barrier size must be increased.

Hanson, Calyton, L. and Rauzi, F. 1977. A pan evaporation as affected by shelter, and a daily prediction equation. Agric. Meteorol., Vol. 18, pp. 27-35.

Abstract

A study of Class A pan evaporation data at two locations on the Northern Great Plains indicated that evaporation from pans protected from the wind by tree shelterbelts was about 14% less than that from unprotected pans.

An equation was developed for estimating daily Class A evaporation from either protected or unprotected pans.

Hofmann, L., Ries, R.E., Power, J.F. and Lorenz, R.J. 1978. Grazing reclaimed stup-mined sites. North Dakota Agric. Expt. Sta. Farm Res., Vol. 36 (1), pp. 3-5.

Abstract

Grazing will become an important use for reclaimed strip-mined land. Little is known about grazing management on these areas or the effect grazing will have on vegetation and soils. A grazing study, initiated in spring 1976, is providing information to determine some of these effects.

Hofmann, L., Ries, R.E., Power, J.F. and Lorenz, R.J. 1977. Effects of grazing intensity on vegetation and animal performance on reclaimed strip-mined land. Fifth Symp. on Surface Mining and Reclamation, Louisville, Kentucky, pp. 306-310.

Abstract

Reclaimed strip-mined land in North Dakota is somewhat fragile and the effects of grazing these lands are unknown. To study these effects, we stocked duplicate sets of pastures at 0, 0.24, 0.48, and 0.72 ha/yearling steer to obtain control, heavy, moderate, and light grazing intensities, respectively, on land reclaimed under the state's 1969 reclamation law near Center, North Dakota. A mixture of cool-season grasses and legumes was seeded in 1973 and not harvested before beginning the study in 1976. During 1976, 3734 kg/ha dry matter was produced on the ungrazed control, and 80, 44, and 32% of the forage was grazed at the heavy, moderate, and light grazing intensities, respectively. The 1976 grazing season was 55 days as compared with 30 days in 1977, which had a much drier spring. In 1977, the heavily grazed pasture had significantly less dry matter than the other treatments when grazing was started. When grazing was stopped, no harvestable forage remained on the heavily grazed pastures. Steers on heavily grazed pastures produced average daily gains of 0.4 kg/head as compared with 0.9 kg/head on the moderately and lightly grazed pastures. Beef production in 1977 equalled 55, 58, and 41 kg/ha for the heavy, moderate, and lightly grazed pastures, respectively. These preliminary data indicated that reclaimed mined land should be suitable for grazing, but additional research is needed to establish good grazing management guidelines for reclaimed land.

Hubbard, W. A. and Sylvester Smoliak. 1953. Effect of contour dykes and furrows on short-grass prairies. J. Range Management, Vol. 6 (1), pp. 56-62.

Abstract

This study took place at the Range Experiment Station at Manyberries, Alberta. Moisture is the limiting factor in range forage production. Precipitation is low, and evapo-transpiration is high but snowmelt runoff is considerable. Terracing, contour furrowing and spring-flood structures were established to control losses during spring runoff. Contour furrows placed at intervals of 2-8 feet cause a significant increase in forage production. In the winter the furrows became filled with ice and snow and were of no value in holding or spreading water. All dykes should be seeded soon after construction to prevent washing and erosion.

Janzen, P.J., Korven, N.A., Harris, G.K., and Lehane, J.J. 1960. Influence of depth of moist soil at seeding time and seasonal rainfall on wheat yields in southwestern Saskatchewan. Res. Branch, Can. Dept. of Agric., Publ. 1090, 10 p.

Abstract

The chief limiting factor in field crop production in southwestern Saskatchewan is lack of available mosture. The water used by dryland crops comes from 1) moisture stored in the soil before seeding and 2) seasonal rainfall. Experiments at Swift Current have shown that an average of 5 to 6 inches of water is needed to produce a minimum yield of 1 or 2 bushels of wheat per acre and 10.5 inches for a 15 bushel crop. Each additional inch of water over 10.5 inches gives an increase of 3 to 5 bushels of wheat per acre up to a yield of 30 bushels. Beyond the 30 bushel level, yield increases per inch of water taper off quickly. The average rainfall during the growing season in Saskatchewan is 5 to 7 inches which is far short of the water necessary to produce a 15 bushel crop. This shows that moisture conservation techniques are very important.

About 21 months elapse from the time a crop is harvested, through a season of summerfallow, to the planting of the succeeding crops. During this period every effort should be made to trap snow and conserve the rain that falls.

The following conclusion and recommendations were made:

1) Lack of adequate moisture is the most important limiting factor in crop production in southwestern Saskatchewan.
2) Observations made during a 22 year study show that the greater the depth of moist soil the greater the average yield of wheat.
3) An estimate of the yield of wheat can be obtained if one knows the depth of moist soil at seeding time and probable seasonal rainfall.
4) In areas of low precipitation, one should not seed stubble land unless the depth of moist soil is at least 18 inches in clay soils, 24 inches in loams and 30 inches in sandy soils at time of seeding.
5) Leave stubble in an upright position to trap snow during the first fall and winter. If weeds are a problem, fall blading destroys them without disturbing the stubble any more than necessary.

Johnson, W.E. 1977. Conservation tillage in Western Canada. J. of Soil and Water Cons. Vol., 32, pp. 61-65.

Abstract

Management of summerfallow begins at harvest time. Adequate spreading of straw, maintenance of maximum stubble height for trapping snow and weed control where needed in the fall must be considered. Phenoxy-herbicides can control fall germinating winter annuals satisfactorily. Chemical summerfallow leaves about 62% of the original residue on the field but full chemical fallow involves high costs to control all weeds and proves uneconomic. Chemical treatment in the fall followed by tillage in the fallow year provided satisfactory erosion control, crop yields and economic returns.

Conserving moisture in the winter is important. Field shelterbelts, strip cropping and a limited amount of surface ridging or surface modification and snow plowing have been used to increase moisture storage. Most of these methods result in variable snow accumulation.

Kibasov, P. 1955. Effectiveness of the various methods of snow retention in Siberia. Zemledeli. Vol 3, pp. 60-61.

Abstract

In order to ascertain the effectiveness of various methods of retaining snow, measurements were made during the winter 1953-154 of the height of snow cover as accumulated by means of (a) brush piles, (b) brush followed by snowplowing, (c) snowplowing only, (d) snow screens (shields) and (e) sunflower fences. A comparison of the snow accumulations by the various methods indicated that the most effective method of retaining snow is by fences. Nevertheless, the author concluded that snow plowing seemed to be more practical for agriculture and proved to be still rather effective in snow retention on cultivated fields.

Kind, R.J. 1976. A critical evaluation of the requirements for model simulation of wind-induced erosion/deposition phenomena such as snow drifting. Atmos. Environment, Pergamon Press, London. Vol. 10, pp 219-227.

Abstract

This paper examines the requirements for correct model simulation, in wind tunnels, of wind-induced erosion and deposition phenomena such as snow drifting.

The similarity analysis draws heavily on physical analysis of the saltation process and on experimental evidence. The important similarity criteria are identified and the limit above which the process is insensitive to Reynolds number is tentatively established. Modelling procedures including a procedure for selecting model particles, are outlined. It will often be impracticable to simultaneously satisfy all the simulation requirements and the compromises involved in such cases are discussed. Simulation of these phenomena in water is shown to be inadvisable.

Kobayashi, Shun'ichi and Tamotu Ishida. 1979. Interaction between wind and snow surface. Boundary-Layer Meteorology, Vol. 16, pp 35-47.

Abstract

The horizontal and vertical wind velocity fluctuations were measured using two sonic anemometers at a height of 135 cm above a snow surface under a transverse snow wave-forming condition. A snow-wave was formed when the wind at a height of 1 cm blew at a speed of more than 7 m s^{-1} after an approximate accumulation of from 10 to 20 cm of new snow on a snowfield. For example, when a snow-wave had a wavelength of 10 cm and a wave height of 15 to 20 cm, the measured horizontal and vertical velocity components showed that they had a frequency peak of 0.7 Hz in coherence and co-spectrum corresponding to this wavelength. The results suggest that wind turbulence and snow-wave formation interact with each other.

Lal, R. and Steppuhn, H. 1979. Fall tillage on the Canadian Prairies; Is it needed. Pres. at 1979 Summer Meeting of ASAE and CSAE, Univ. of Manitoba, Winnipeg, Canada, 17 pp.

Abstract

The question of value for fall tillage on the Canadian Prairies relates to its necessity: 1) to disperse and incorporate crop residues, 2) to control weeds, and 3) to enhance infiltration and soil storage of winter precipitation. Fall tillage to alleviate the problem of crop residues may be unnecessary if suitable seeding equipment can be developed and utilized. Fall tillage to control weeds appears unnecessary since the use of herbicides is just as effective. Fall tillage does not increase infiltration of over-winter precipitation since it tends to lodge standing stubble reducing its snow trapping potential.

Lee, Lang Wah. 1975. Sublimation of snow in turbulent atmosphere. Dissertation, Dept. Mechanical Engineering, Univ. of Wyoming, Laramie, Wyoming. 172 p.

Abstract

The redistribution and preferential deposition of snow by the wind poses problems for transportation as well as affecting water balance for wind swept watersheds by increasing the sublimation losses of the snow pack. Much of the basic engineering development of devices to efficiently control blowing snow has been directed towards the protection of transportation sites as in the case of the extensive snow fence system that was recently designed and installed by Wyoming to protect portions of Interstate Highway 80. It is quite effective technqiues to artificially induct drifting on a watershed may become an economical consideration in snow pack management in certain regions. For instance, the large snow fence system used on I-80 has a measured water-equivalent storage of the order of 1000 ft^3 per linear foot of fence system at the time of peak accumulation. One of the most critical factors in determining the desired capacity of a snow control system, whether the objective is to increase the output of a watershed, reclaim strip mined areas, or the traditional protection of a site, is to determine some characteristic sublimation distance since the capacity is essentially proportional to this distance.

Lindwall, C.W., Zentner, R.P. and Anderson, D.T. 1979. Conservation characteristics of minimum tillage systems. Pres. at the 1979 summer meeting of the ASAE and CSAE, June 24-27, 1979, Winnipeg, Manitoba, 10 p.

Abstract

Eight summerfallow systems for spring wheat production were compared in terms of moisture and crop residue conservation, yield, economics, and energy efficiency. Minimum tillage improved moisture conservation by snow trapping, lowered energy inputs, and increased yields; however, repeated application of herbicides is not now economical.

Lull, H.W. and Orr, H.K. 1950. Induced snow drifting for water storage. J. Forestry, Vol. 48, pp. 179-181.

Abstract

If water is the form of snow drifts can be stored on watersheds some of the critical limitations of western irrigation agriculture may be overcome. The authors present the results of preliminary investigations on natural and artificial drifting of snow together with suggestions as to how induced drifting may improve the usefulness of runoff.

Lyster, Bryan. 1976. Grass strips replace summerfallow. Country Guide. Nov., 1976. pp. 16-18.

Abstract

In dry regions, a summerfallow crop is usually a safer bet than a stubble crop because fallow often contains extra moisture reserves. However, U.S. researchers have found that grass strips trap enough snow to build up as much moisture in stubble land over one winter as summerfallow does over 20 months. The strip should be placed 40-60 feet apart and it is advised that farmers should space the strips to accomodate then equipment. Crop yields from protected stubble land equalled conventional fallow yields, but they surpassed conventional stubble yields by a wide margin. At Swift Current, Saskatchewan researchers left a 10" high stubble on one round with the swather and only a 6" high stubble on the next creating a set of mini - windbreaks in the field. Results of this technique varied.

Marks, R.J. 1967. Windbreaks and shelterbelts. Cooperative Exp. Station, Montana State College, Bayeman. Bull No. 318.

Abstract

Windbreaks planted around farmsteads protect buildings from winter and summer winds. They have cut fuel costs approximately 36 percent, increased yields of vegetables, berries, tree fruits and made the farm a more comfortable place to live. Field shelterbelts add moisture by holding and keeping snow distributed evenly over the protected areas. They reduce wind velocity for a distance 20 times the height of the trees. They reduce crop flattening, keep newly planted seed from blowing out and young stands from being cut off by blowing soil. They protect crops from drying summer winds and reduce loss of moisture by evaporation.

Martinelli, M. 1966. Possibilities of snowpack management in alpine areas. Proceed. Int. Symp. on Forest Hyrdology, Pennsylvania State University, Pennsylvania, Aug. 1979. pp. 225-230.

Abstract

The primary objective of watershed management of alpine areas in the Rocky Mountains should be to increase summer streamflow. Operational procedures that appear to have some chance for success include weather modification-especially seeding of orographic storms; intentional avalanching to store snow in high elevation, shaded valleys; reshaping natural terrain features to improve their snow trapping efficiency and capacity; control of snowmelt by the addition of materials to the snow surface; and snow fences or other artificial wind barriers to increase the amount of snow in areas of natural accumulation or to help shape terrain for more efficient snow storage.

Snow fences at two windy sites-one along a major ridge, the other on a gentle lee slope-have increased natural snow accumulation by about one acre foot of water per 100 to 125 ft of fence measured in early July. Fences are being studied at two additional sites.

Research is recommended on windflow and snowdrift patterns in irregular terrain as a basis for model studies and on procedure and techniques for accumulating snow by intentional avalanching.

Martinelli, M.J. 1965. Accumulation of snow in Alpine areas of Central Colorado and means of influencing it. J. Glaciol, Vol. 5, pp. 625-636.

Abstract

The accumulation of snow in terrain depressions was studied in an alpine basin in central Colorado. Snow fences were constructed up-wind of several natural catchments to see if such barriers could be used in combination with terrain features to produce snow fields that would persist until late summer. At 3 of the 6 test sites, fences increased snow depths appreciably and the snow fields presisted longer than usual. At the other test sites snow depths were increased close behind the fences but were decreased farther down-wind with no net increase in the amount of snow caught.

Matthews, G.D. 1947. Progress Report 1937-47. Dominion Experimental Station, Scott, Sask. pp. 28-29.

Abstract

Snow constitutes approximately twenty-five per cent of the annual precipitation received in this area. Most of this snow is of little value in crop production because it is swept from the open fields and deposited around obstructions such as fence rows, shelterbelts, buildings and coulees by the winter winds. Shelterbelts of trees around gardens accumulate large drifts of snow and the beneficial effect of the resulting moisture has long been realized and its value appreciated. Because of the marked benefits received by garden crops, as a result of the accumulated snow, this Station initiated a number of studies designed to trap the snow, which ordinarily was blown from the open fields.

A number of different methods to artifically accumulate snow on the open fields were tested. Snow fences of various types were used but these were found unsatifactory because of the very non-uniform snow cover produced. The result was strips of very wet and almost dry soil which prevented normal working of the land and non-uniformity in the succeeding crop. Attempts at arranging the fences close together so that the resulting drifts would cover the entire field surface were found to be too expensive to be of any practical value, except for certain specialized purposes.

To overcome these difficulties attempts were made at ridging the snow with the hope that the ridges would accumulate an even snow cover over the fields. In order to produce the ridges a cheap workable snow plough was the first requirement. Two types of ploughs were evolved at this Station, a pull-type, suitable for use with horses or tractor, and a push-type mounted on a tractor.

Matthews, G.D. 1940. Snow utilization in prairie agriculture. Pub. No. 696, Farmers Bull. 95. Canadian Dept. of Agriculture Res. Branch. 21 pp.

Abstract

The results obtained at Scott, Saskatchewan from ridging snow in 1938-40 were consistent with other results obtained in previous years. Grain crops on stubble were definately helped with snow-ploughing increasing wheat 37.6 per cent, oats 51.6 per cent, and barley 34.7 per cent. Yields in grain by snow ridging on summerfallow were not influenced to any great extent, being 3 per cent greater for wheat, 5 per cent for oats and 11 percent for barley. The main objective of snow ridging on summerfallow is to give the grain crop a start in the spring, and to aid in control of soil drifting. The use of artificial barriers such as brush or snowfence for snow control was found to be complicated and economically difficult.

McCalla, T.M., and Army, T.J. 1961. Stubble mulch farming. Adv. Agron., Vol. 13 pp. 125-196.

Abstract

The chief merit of stubble mulching appears to be its effect in reducing runoff and erosion by wind and water. Also, its value for snow catch and overwinter moisture storage efficiency should not be overlooked. Because of the inability to keep adequate cover of plant residues or growing crops at all times on the land, it is necessary to use stubble mulching along with other good conservation practices. Stubble mulching should frequently be used in a system of conservation farming with practices such as terraces, contouring, grassed waterways, stripcropping, and other proved cropping systems.

When stubble mulching is incorporated into a system of farming employing patterned windbreaks, good cropping and fertilizing practices, cover crops, contouring, and rotations using grass legumes, a good job of protecting the land against erosion by wind and water usually can be accomplished.

In some areas it may be possible occasionally to use stubble mulching alone or with one or two simple conservation practices and do a reasonably good job of soil and water conservation. In some areas of the Pacific Northwest, topography may be such that present types of terraces and contouring may not be practical. Then stubble mulching must be used alone. Even here it can be combined with rotations. Under such circumstances, a great deal of effort and skill are necessary if adequate residue cover is to be maintained on the land at all times.

Under some conditions where there is a limited amount of residues it may be necessary to use emergency wind erosion control practices such as chiseling to produce clods which will give the land temporary protection.

McKay, G.A. and Thompson, H.A. 1968. Snowcover in the Prairie Provinces of Canada. Trans. of the Am. Soc. Agr. Eng., pp. 812-815.

Abstract

Snow is the main source of manageable fresh water in Northern latitudes. Water from melting snowcover provides most of the streamflow, replenishes stock water, and percolates into the soil from where it is available to crops. Snowfall over an area tends to be more uniform than rainfall. However, since it is moved by the wind it is difficult to obtain representative measurements. Local variation in topography and vegetative cover cause major departures from the average snow depth.

McMartin, W., Haas, H.J. and Willis, W.O. 1970. Economics of forage production on level benches in the Northern Plains. J. Soil and Water Cons., Vol. 25 (5), pp. 185-189.

Abstract

Wheat was harvested for 3 years from sample areas at regular intervals in rows perpendicular to 14 single-row shelterbelts. Yields were lowest near the tree row and increased out to a distance of 5 H (height of trees) from the tree row. Maximum average yield was 40 bushels per acre at 5 H. The weighted average yield for the area from the tree row to 13 H was 35 bushels per acre, 3 bushels less than the check-area yield. Excluding the area occupied by the tree row raised the average yield for the area from 1 H to 13 H to 38 bushels, the same as the check area. Net result for an entire field was a slight reduction in wheat production. As trees grew taller, wheat losses increased gradually because of greater tree competition for soil moisture and nutrients. The study revealed that shelterbelts in the Northern Great Plains may prevent soil erosion, trap snow, provide habitat for wildlife, and provide esthetic qualities, but their use as a means of increasing wheat yields is not justified.

McMartin, W., Frank, A.B. and Heintz, R.H. 1974. Economics of shelterbelt influence on wheat yields in North Dakota. J. Soil and Water Cons., Vol. 29, pp. 87-91.

Abstract

The report describes level benches, their construction and their effect on yields of alfalfa and other crops. Costs and returns of level benches for forage production are discussed. On slopes of 2 percent, for example, net returns from alfalfa might reach $1,091 per 100 acres, while on 6-percent slopes benches of the same width would net about $529. Factors affecting the rate of adoption of benches-include soil, topography, government conservation programs and alternative uses for land.

McMaxtin, W., Frank, A.B. and Heintz, R.H. 1974. Economics of shelterbelt influence on wheat yields in North Dakota. J. Soil and Water Cons., Vol. 29, pp. 87-91.

Abstract

The report describes level benches, their construction and their effect on yields of alfalfa and other crops. Costs and returns of level benches for forage production are discussed. On slopes of 2 percent, for example, net returns from alfalfa might reach $1,091 per 100 acres, while on 6-percent slopes benches of the same width would net about $529. Factors affecting the rate of adoption of benches-include soil, topography, government conservation programs and alternative uses for land.

Michalyna, W. and Hedlin, R.A. 1961. A study of moisture storage and nitrate accumulation in soil as related to wheat yields on four cropping sequences. Can. J. of Soil Sci., Vol. 41(1), pp. 5-15.

Abstract

On a clay soil at Winnipeg, Manitoba, at the University of Manitoba, four cropping sequences, namely: 1) fallow wheat; 2) fallow, wheat, wheat; 3) fallow, wheat, wheat, wheat; 4) wheat continuous have been under study since 1919. During the years 1956, 1957, 1958 a detailed study of the relationship of wheat yields on these sequences to moisture consumption, nitrate accumulation, moisture storage and fertilizer use was undertaken. In general, yields were higher on fallowed than on non-fallowed plots. The higher yields on fallowed plots were, in part, related to nitrate accumulation during the fallow year. The yield differential between fallowed and non-fallowed plots was reduced by mineral fertilizer and manure treatments. Where no fertilizer was used the greatest wheat production in bushels per acres per year was on the fall-wheat-wheat sequence. When fertilized or manured, the greatest production occurred on the wheat continuous plots.

Rapid accumulation of moisture took place between harvest and the following spring. As a result, during years 1956, 1957 and 1958, there was only an average of 0.7 inches more available moisture to a 4-foot depth on fallow plots at seeding time than on plots which had been cropped the previous year.

Mellor, M. 1965. Blowing snow. Cold Regions Science and Engineering Part III, Section A3C. CRREL, 77 p.

Abstract

Wind-blown snow causes a variety of problems over the great areas of the earth where it is commonly experienced. While snow is actually blowing, outdoor activities, including transport, are curtailed and electrical disturbances, such as radio noise, are experienced. At the of a period of blowing snow, many areas (e.g., roads and avalanche paths) are found to be covered by unwanted deposits of snow, while other places (such as arable land or ski trails) may have been denuded of much-wanted snow. Redistribution of snow by winds is also a factor to be considered in the study of glaciers and the management of drainage basins.

Simple measures for the control of blwoing snow, notably snow fences, have long been used, but the methods currently available for abating the nuisance of blowing snow (or even turning it to advantage) are far from adequate in a period of increasingly vigorous human activity in snow-covered regions. Fortunately there are in progress numerous studies which should lead to an early improvement in the situation. Field studies are yielding data which clarify the physical situation, while the general theory of two-phase flow (i.e., fluids and solid particles) is exciting interest in a number of technical fields. Finally, techniques for the execution and interpretation of model and prototype investigations on drift control measures are being refined.

Mickelson, R.H., Cox, M.B. and Musick, J. 1964. Runoff water spreading on leveled cropland. J. Soil and Water Cons., Vol. 20, pp. 57-60.

Abstract

A level pan sytem constructed in broad, natural drainageways can intercept, spread, and store storm runoff. These pans ranged in size from 2.5 to 6.6 acres and all pans were diked to retain runoff. Diversion structures were constructed to funnel all runoff through flumes equipped with recorders to measure the quantities that flowed through the drainageway. The pans were cropped every year. The system provided 4 to 7 inches of additional available water on the leveled areas and this additional moisture caused substantial increases in crop yields.

Molberg, E.S. and Hay, J.R. 1968. Chemical weed control on summerfallow. Can. J. of Soil Sci., Vol. 48, pp. 255-263.

Abstract

Use of residual and contact herbicides was compared with cultivation for weed control on summerfallow on Regina heavy clay from 1964 to 1967, inclusive. A single spring application of desmetryne (2-isopropylamino-4-methylamino-6-methylthio-s-triazine) at 3 kg/ha gave 77 to 90% weed control without reducing wheat yields the following year. Disadvantages were incomplete weed control, and herbicides persistence in the soil with thinning of the following wheat crop in some years.

Three or four applications of paraquat (1,1'-dimethyl-4,4-bipyridinium (salt) at 1 kg/ha gave weed control equal to cultivation of summerfallow. Chemical moisture conservation, NO_3-N accumulation and crop yields. Chemical summerfallow conserved 91% of the original crop residues compared with 24% for cultivated summerfallow. This extra crop residue was sufficient to prevent serious soil erosion from wind. Paraquat is currently too expensive to compete with cultivation.

Neff, E.L. 1973. Water storage capacity of contour furrows in Montana. J. Range Manage., Vol. 26, pp. 298-301.

Abstract

A field study in eastern Montana related water storage capacity to furrow age. New contour furrows have a water storage capacity of nearly 1 inch, but this decreased with time owing to natural weathering, intrafurrow dam failure, and furrow breaching. Contour furrows have an average effective life of 25 years, but this ranges from less than 20 years to more than 35 years depending on initial construction. A new furrowing machine design is suggested that would leave intrafurrow dams of undisturbed soil material, resulting in furrows with either the same storage capacity but a greatly reduced cost per acre, or over twice the storage capacity at about the same cost per acre as furrows built by a Model B machine. The Model B furrowing machine is the most common machine used.

Neff, E.L. 1979. Snow trapping by contour furrows in Southeastern Montana. At press. Journal of Range Manage.

Abstract

Contour furrows on fine-textured range sites in southeastern Montana caught an annual average of 22 mm more snow water equivalent than nearby nonfurrowed areas. In addition, the furrows held snowmelt onsite in the spring and significantly reduced winter runoff in nearly half of the years of record. Except in years of much below normal winter precipitation, however, the winter runoff from furrowed areas was still more than adequate to fill well-designed stockponds.

Neff, E.L. and Wight, J.R. 1977. Overwinter soil water recharge and herbage production as influenced by contour furrowing on eastern Montana rangelands. J. Range Manage., Vol. 30, pp. 193-195.

Abstract

On fine-textured range sites in Southwestern Montana, contour furrowing increased average overwinter soil water recharge 11mm on a saline-upland range site and 39 mm on a panspot range site. Increased recharge resulted from decreased late fall and early spring runoff and increased snow accumulation. Overwinter recharge was a function of both antecedent soil water and the amount of water available for recharge. Herbage production was significantly (r = 0.89) related to spring soil water content. Furrows were constructed using an Arcadia Model B furrower that gave furrows about 50 cm wide, 15 cm deep and 150 cm between furrows.

Nicholaichuk, W. and Norum, D.I. 1975. Snow management on the Canadian Prairies. In Snow Management on the Great Plains Symposium. Great Plains Agricultural Council Publication No. 73. Lincoln, Nebraska. pp. 118-127.

Abstract

Snow in the main source of manageable fresh water on the Canadian prairies. It provides a source for replenishing reservoirs, streamflow and soil moisture. Generally, snow constitutes over 25% of the amount of precipitation received on the Canadian prairies. The water equivalent of snow is about 3 1/2 to 5 inches.

Recognizing the potential of snow as an additional source of soil moisture, attempts have been made to manage the resource by means of (1) snow ridging, (2) the use of shelterbelts and (3) stubble stands at alternate heights. These are the only methdods of snow management that have been investigated and documented in Western Canada.

This proper outlines the distribution of snow on the prairies, review the progress made with regard to the management of snow and discuss some of the considerations that should be taken into account for further investigations.

Pawlowski, S. and Smith, A.D. 1966. Sunflowers instead of fallow. Crops and Soils, Vol. 19 (2), pp. 6-7.

Abstract

Sunflowers grown under test in widely spaced rows are making continous cropping possible in dry areas of Alberta and Saskatchewan once limited to a wheat-fallow rotation. The stalks stand in the winter to trap snow and reduce evaporation. The rows are planted 8 to 16 feet apart. Because sunflowers can be harvested the year they are seeded, they give the farmer income from all his land every year. In addition sunflower stand through the winter better than other crops.

Pelton, W.L. 1976. The effect of windbreak on wind travel, evaporation and wheat yield. Can. J. Plant Sci., Vol. 47, pp. 209-214.

Abstract

A windbreak was erected in a wheat field during the growing seasons of 1960 to 1964 inclusive. The effect of this barrier on wind travel, evaporation, and wheat yield was measured. The use of snow fencing, erected each year after seeding, eliminated the effect of snow accumulation on the grain yield of sheltered fields.

The windbreak reduced wind travel by 15 to 49% during the five-year test period and led to reductions of 12 to 23% in evaporation from Bellani plates. Yields within the sheltered area ranged from 24 to 43% above check yields. Maximum grain production was obtained in the area of maximum wind and evaporation reduction. However, yields in general were extremely variable throughout the test area during individual years, and from year to year. The wide variations in yield suggest that the effects of windbreaks on other environmental factors should be considered in studies of this nature.

Pelton, W.L. 1976. Windbreak studies on the Canadian Prairie. In. Richard W. Tinus (ed). Proceed. of the Symposium: Shelterbelts on the Great Plains. Great Plains Agr. Council Publ. No. 78. pp. 64-68.

Abstract

Research concerning the influence of windbreaks on wheat production in western Canada is reviewed. Natural and artificial windbreaks reduce wind travel, evaporation, and soil drifting and increase the amount of moisture available to crops within the sheltered zone as a result of snow accumulation. However, their overall influence on crop yields is limited.

Pugh, H.D. and Price, W.J. 1954. Snow drifting and the use of snow fences. Polar Record, Vol. 7 (47), pp. 4-23.

Abstract

The drifting of snow is an example of the general phenomenon of transportation of solid particles by a fluid moving over a surface composed of such particles. Movement of the particles can take place in three ways: either by suspension in the stream, or by saltation, or by creeping along the surface. Drifting occurs even at air temperatures of $0^{o}C$ but occurs more frequently when the temperature is below freezing and the snow is dry. Wind speed needs to be at least 15 Km/h before drifting occurs.

There are three types of snow fences:

1) leading fences - lead snow from the protected area to places such as hollows in the ground, which act as snow reseroirs.
   - deflect the air stream without reducing its velocity.

2) blower fences - located at short distance (10-24 ft) from the area to be protected.
   - may be solid or include large openings or gaps.
   - snow-bearing wind is deflected downwards.

3) collecting fence - most widely used.
   - causes snow to be deposited before it reaches the protected area.

Power, J.F., Ries, R.E. and Sandoval, F.M. 1976. Use of soil materials on spoils - effect of thickness and quality. North Dakota Agric. Expt. Sta. Farm Res. Vol. 34 (1), pp. 23-24.

Abstract

Both thickness and quality of soil material spread on spoils affect potential crop yields. On sodic spoils, as little as two inches of soil material is highly beneficial, but at least 30 inches seem to be required for maximum production.

Price, W.J. 1961. The effect of the characteristics of snow fences on the quantity and shape of the deposited snow. IASH Pub. No. 54. General Assy. of Helsinki, 1960. pp. 89-98.

Abstract

In order to devise snow fences to protect roads from drifting snow, the British Road Research Laboratory has during recent years, carried out full-scale experiments in Scotland to see how the size and shape of the drift deposited by a snow fence is affected by the characteristics of the fence. This paper gives the results of these investigations.

The profiles of the drifts produced by the fences are described at various stages in their growth. At all stages, the density ratio (frontal area of solid part of fence divided by total frontal area) was the most important factor in determining the volume of snow deposited by a fence, the greatest volume occurring at a density ratio of 0.4. The effect of fence height (h metres) was studied over the range 1.25 to 1.87 m at a density ratio of 0.5. When the fence was saturated with snow, the maximum height of the drift was 1.14 h and its legnth was 22 + 6.5 h. With wind normal to the fence there was no significant difference in the drifts whether the slats were vertical or horizontal. The effect of slat width was studied at a density ratio of 0.42 and found unimportant over the range from 2.5 to 22.5 cm. At greater widths, less snow was deposited directly behind each slat.

When the fences were saturated with snow, the shape of the profile of the drift perpendicular to the fence could be represented graphically by part of the perimeter of one petal of a mathematical rose. The constants of the polar equation of this curve were related to the density ratio of the fence, its height, and the size and arrangement of the material in it.

Radok, U. 1977. Snow drift. Jour. Galciology, Vol. 19 (8). pp. 123-139.

Abstract

Wind-blown snow represents an age-old problem in the applied glaciology of most higher-latitude regions, but its physical intricacies first received attention in esoteric discussions on the long-term mass balance of polar ice sheets. Measurements on the uniform unlimited surface of such ice sheets have shown good agreement, at least over a limited height range, with estimates for the concentration and flux of drift snow as a function of height and wind velocity based on turbulence theory. An alternative theory, developed concurrently from wind-tunnel results and field observations in Siberia, is discussed on the basis of its most recent exposition. Basic questions requiring further study include drift-snow concentrations at considerable heights, drift evaporation, and electrical phenomena.

The main practical aspects of snow drift relate to the prevention of excess accumulation on roads, railway lines, and avalanche slopes; and to the encouragement of accumulation in fields and forests, and other locations where frost protection and/or storage of water is desired. The methods used are reviewed; they are beginning to rely on physical concepts and theories rather than solely on empirical formulae derived from engineering experiments.

In regions of positive surface mass balance, buildings and other structures tend to become obliterated by snow drift. An important factor of this process is the fall-out of snow in the retarded flow on the windward side of the structure. Some recent attempts to measure and calculate that fall-out are discussed.

Radok, U. 1968. Deposition and erosion of snow by the wind. U.S. Corps of Engineers. CRREL Res. Report No. 230. 23 p.

Abstract

The theories of uniform and non-uniform drifting snow are summarized with special emphasis on drift transport as a function of wind velocity. Using the work of Owen (1964) and the observations of the Byrd Station Snow Drift Project (Budd, Dingle and Radok, 1966) it is confirmed that the snow drift process involves a mobile surface layer of saltating particles, with a self-regulating thickness depending only on the surface stress and not on the snow concentration in the free air stream. It is shown to be a characteristic of snow (in contrast to sand or silt) that saltation and suspension drift occur side by-side and that the latter reaches predominance as the wind velocity rises through the most common range of surface values. Theoretical reasons and observational evidence are produced for the view that deposition or erosion occurs on the snow surface during snow drift primarily as the result of mass flux convergence or divergence in the free air stream. This implies that the associated vertical mass flux penetrates the saltation layer which moves up or down with the snow surface. The survey concludes with suggestions for the experimental study of snow deposition and erosion in terms of the free air flow field and for a study of pneumatic particle transport in terms of saltation and of its electrical effects.

Rauzi, Frank. 1975. Snow management for water conservation in Wyoming. In Snow Management on the Great Plains. Great Plains Agric. Council Pub. No. 73. Lincoln, Nebraska. pp 180-186.

Abstract

Snow if properly managed, is a resource with much potential for Great Plains agriculture. Yet, this resource is regarded by many as a nuisance during the winter season. Because snow is not managed as a resource, snowmelt runoff is wasted all to frequently and can cause or contribute to flooding.

One way to manage snow for beneficial use is by using level benches. Level benches differ from conventional terraces in that their channels are much wider to provide more uniform distribution of collected water. These benches are level in all directions and diked at their ends and on their downslope side to give them more water storage capacity. Level benches can hold and store water for crop production from both snowmelt and torrential rains.

Haas et al. and Hass and Willis have shown that level benches increased water storage and doubled alfalfa and bromegrass yields as compared with adjacent sloping lands. McMartin et al. stated that using level benches would be economical for riasingalfalfa for a cash crop or livestock feed. For alfalfa production on 1 and 2% slopes, the net return from benches, without contributing areas, ranged from about $900 to $1300/100A. Returns for benches with a 1:1 contributing area ranged from $590 to $796 (6). These returns were calculated assuming an alfalfa price at $17/T.

Rauzi, F. and Lange, R.L. 1957. Range pitting. Whats new in Crops and Soils. Vol. 9 (9) 1 p.

Abstract

Range pitting, where native vegetation is a mixture of shortgrasses and midgrasses, has increased forage production and grazing capacity on the shortgrass plains of Wyoming. The pitting operation leaves the land surface with a waffle-like appearance and the newly formed pits hold about 0.3 inches of rain as well as snow in the winter. Pitting increased the grazing capacity by one-third and 33% more perennial grass was left at the end of the grazing season on the pitted pastures than on those not treated. Pitting also changes the vegetational composition of the grasses. Midgrasses on the pastures increased and shortgrasses decreased during the first 8 years of treatment. After a 13 year study the pits were ineffective, therefore pitting every 10 years is recommended.

Rauzi, F., Landers, L. and Gray, R. 1973. Level benches for Northern Plains Rangelands. Montana Farmer-Stockman. Vol. 60 (13), pp. 22-23.

Abstract

In an effort to obtain better use of rainfall and snow, level benches were constructed at the Gillette Substation of the Wyoming Agricultural Experiment Station in 1970. Level benches are modified terraces that are level in all directions and diked at the ends to hold all of the water. The benches conserve soil and store water trapped on the bench. In the first crop year of 1971, alfalfa yields on the benches was increased up to 3/4 ton per acre. Yields in 1972 were only slightly better than check plots.

Rechard, P.A. and Larson, L.W. 1971. The use of snow fences for shielding precipitation gages. Proc. of 39th Western Snow Conference, Billings, Montana. pp. 56-62.

Abstract

The reasons for wanting to measure precipitation are many and varied but basically the data are required as an essential element for climatology, hydrology and meteorology studies. Since wind has a great effect on gage catch a wind shield is needed. Snow fence material is the standard 4-foot vertical-lath highway-type fencing with about 50 percent density (the optimum open density). A gap of six inches is left below the fence because other research has shown that a gap of less than six inches allows snow to accumulate against the fence and "streamline" it prematurely. If the gap is greater than one foot, the snow collecting capacity of the fence is reduced.

Ries, R.E., Sandoval, F.M. and Power, J.F. 1978. Re-establishment of grasses on land disturbed by mining in the Northern Great Plains. Proc. of First Int. Rangeland Congress pp. 700-703.

Abstract

In this study topsoil replacement was essential to stand establishment and productivity on mine spoil. Fertilizer application increased stand production but did not influence stand density. Selection of grass species that are readily established is essential to establishing fully stocked initial stands.

Ries, R.E., Sandoval, F.M., Power, J.F. and Willis, W.O. 1976. Perennial forage species response to sodium and magnesium sulfate in mine spoil. Fourth Symp. on Surface Mining and Reclamation, Louisville, Kentucky, pp. 177-183.

Abstract

Magnesium and sodium sulfate are the principal salts in lignite and subbituminous coal spoils originating from the Fort Union geologic group in North Dakota, Montana, and Wyoming. Survival and growth of eight perennial forage species as affected by these salts were studied in growth chambers at three stages of plant development -- germination, emergence-establishment, and growth. For the emergence-establishment and growth of two different textures from Peabody Coal Co.'s Big Sky Mine, near Colstrip, Montana. Results showed that plant species responded differently to similar kinds or concentrations of salt, and that individual species responded differently to a given salt at different development stages. In general, three types of plant responses were observed: (1) no effect of kind or concentration of salt; (2) sensitive to increased salt concentration but not to specific kind of salt; and (3) sensitive to both kind and concentration of salt. In some instances growth of some species was affected by spoil texture. Results indicate that stands of such species may become established or survive in field plantings only under certain restricted conditions.

This study provides basic information concerning probable species response at different growth stages to kind and concentration of salt and to spoil texture. From this information, methods of spoil and vegetation management can be developed for field testing and use in semiarid and arid coal fields.

Ries, R.E., Sandoval, F.M. and Power, J.F. 1977. Reclamation of disturbed lands in the lignite area of the Northern Plains. In Proc., 1977 Symp. on Technology and Use of Lignite. ERDA-UND. Grand Forks, N.D. pp. 309-327.

Abstract

Surface mining for lignite in the Northern Plains is expanding to meet energy needs. The commitment to reclaim mined land to a high level of production has stimulated interest in and need for reclamation technology.

Recommended procedures include premining soil and overburden laboratory analysis, removing and stockpiling suitable soil materials (up to 5 feet if available), removing overburden, extracting coal, reshaping spoil, replacing stockpiked soil material, fertilizing and seeding to either cropland or rangeland mixture of plant species.

If the recommended procedures are followed, the probability for high level reclamation is promising. Some problems still exist for which there is less knowledge -- they include piping erosion, subsidence, need for more reliable vegetation establishment practises, and the assurance of sustained productivity under various land uses.

Current research is directed towards determining soil thickness requirements needed over undesirable mine spoil for permanent reclamation. The use of chemical amendments is also being studied and may have a role, especially where suitable soil is not available in sufficient quantities to cover sodic spoils. Numerous plant species are being evaluated. Irrigation to supplement natural precipitation during the period of establishment is also being studied.

Ries, R.E., Power, J.R. and Sandoval, F.M. 1976. Potential use of supplemental irrigation for establishment of vegetation on surface mined lands. North Dakota Agric. Expt. Sta. Farm Res., Vol. 34(1), pp. 21-22.

Abstract

Irrigation is a potential reclamation tool that may have application in establishing vegetation on surface disturbed lands, especially perennial rangeland vegetation. Research concerning the use of supplemental irrigation has been initiated, and continued study will better define the benefits and techniques of supplemental irrigation for the establishment of plants and plant communities on surface-mined lands in North Dakota.

Roots, E.F. and Swithinbank, C.W.M. 1955. Snowdrifts around buildings. Polar Record, Vol. 7, 380-387.

Abstract

The critical factor controlling the size of a lee snowdrift is the height of the highest obstruction broad enough to cause significant disruption of the airflow pattern. For obstructions up to 2 m. high, the size of the drift increases in roughly linear proportion with the height of the object. For higher obstructions which project above the heavily snow-laden lower layers of air the proportionate increase in the size of the drift falls considerably.

Rodenko, G. 1970. Protecting crop bands. Zemledeliya, No. 11, 3 p.

Abstract

Bands of sunflowers and mustard are used to overcome drought effects on crops. Spring wheat yields increased from 19,900 kg/acre in fallow without bands to 23,900 for fields with bands. General consideration was also given to raising yields on 2nd and 3rd year crops and to the maintenance of the fertility of the soil. Sunflowers make good bands since they tolerate strong winds and resist insects and diseases. The best time to seed sunflowers is from June 25-July 5. Bands should not be over 12 meters apart to assure uniform snow coverage. The proper technique for seeding bands among grain crops is listed below:

1) Spring wheat is seeded in a 3-gang drill. In the first two passes wheat is seeded through all 3 gangs. Every third pass 1/2 of the centre gang is cut off. As a result every 30.6 metres there is an unseeded strip 1.8 m wide which accounts for 6% of the seeded acreage.

2) After the wheat has emerged the non-seeded strip are cultivated several times until June 25. Sunflowers are seeded from June 25 to July 5 with a special seeder. Rows are 15 cm apart and 75 cm from the wheat crop. Techniques are also being worked out for bands in fields of corn.

Rosenberg, N.J. 1966. Influence of snow fence and corn windbreaks on microclimate and growth of irrigated sugar beets. Agron. J., Vol. 58, pp. 469-475.

Abstract

During the 1964 growing season, irrigated sugar beets were sheltered against wind at the Scotts Bluff Experiment Station, University of Nebraska, by snow fence erected at planting time and by double rows of corn planted as early in the season as possible.

Germination was improved in areas protected by snow fence, although the effect was not uniform throughout the sheltered area. Both types of shelter increased root and total weight of beets over that in an unsheltered site. Top weight was not affected. Root/top ratio was greatest in corn-sheltered beets. Sugar content at harvest was depressed in beets grown in the snow fence sheltered areas. Press juice samples of corn-sheltered beets showed greatest purity.

Air temperature above the sheltered beets was higher by day and lower by night than in the open site. Absolute humidity content of air above the beets was not influenced by shelter.

The snow fence shelter altered the wind profile, raising the zero plane to within the top quarter of the sheltered beet canopy. Wind shear in that plot suggested a reduction in turbulent exchange. In the corn-sheltered plot, wind profiles were similar to those in the open with a moderate reduction of wind speed at the two levels above the canopy at which measurements were made. An intensification of temperature lapse rate in the corn shelter may have increased rate and extent of turbulent exchange processes.

Rylov, S.P. 1969. Snow cover evaporation in the semidesert zone of Kazakhstan. Trans. of the Kazakh Hydrometeorological Scientific Research Institute (Trudy Kaz NIGMI), No. 32, pp. 64-77.

Abstract

According to observations at the West Kazakhstan runoff station, the rate of evaporation from snow is 0.08 - 0.12 mm/day in winter and 0.40 - 0.60 mm/day in spring. The computed evaporation from snow in the semidesert zone in the December - March period ranges from 15 mm in the north to 24 - 30 mm in the south. The losses in the storage through evaporation in the semidesert zone (West Kazakhstan runoff station) are 15% in winter, and 5% for the non-reduced evaporation depth and 18% for the reduced evaporation depth during the snow melting period. Verification of the existing methods of computing evaporation from snow in the semidesert zone of Kazakhstan proved the most accurate and simplest method of computation; it is based on the vapor pressure deficit.

Sandoval, F.M. 1978. Deep plowing improved sodic claypan soils. North Dakota Agricultural Experiment Station Farm Research, Vol. 35 (4), pp. 15-18.

Abstract

Sodic claypan soils of western North Dakota (also called Natriborall or Solonetzic) are improved by deep plowing. Plowing 24 to 30 inches deep crumbles the dense subsoil layer and brings up natural gypsum (calcium sulfate) from below the pan, which permits a physical-chemical change to form a better soil. Density is reduced, permeability and water holding capacity are increased, and crop production is benefited.

Sandoval, F.M. and Jacober, F.C. 1977. Deep plowing - cure for sodic claypan. Crop and Soils Magazine April - May, pp. 9-10.

Abstract

The results of deep plowing seem to permanently alleviate the problem of sodic claypan soils. Soils that were deep plowed were still producing good crop yields after 9 years. Usually about 6 inches or less under the surface of this soil is a dense layer that is high in absorbed or exchangeable Na. Immediately below this dense sodic layer of soil is a zone of gypsum. Plowing to a depth of 24 to 30 inches breaks up the top layer and mixes the gypsum so that calcium replaces the sodium in the soil and subsequently precipitation leaches the sodium.

Sandoval, F.M., Bond, J.J., Power, J.F. and Willis, W.O. 1973. Lignite mine spoils in the Northern Great Plains - characteristics and potential for reclamation. Research and Applied Technology Symp. on Mined-land Reclamation. Pittsburgh, Pa., pp. 117-133.

Abstract

Overburden materials left as spoils on the surface after strip mining for lignite and subbituminous coal in North Dakota, Montana, and Wyoming were studied in the laboratory and in the field to avaluate their potential for reclamation and revegetation. Results show that the physiochemical properties of materials, presently left as spoils, provide a very poor environment for vegetative growth. Materials from the Tongue River and Sentinel Butte Formations within the Fort Union group were often extremely fine-textured (Montmorillonitic), moderately saline, and highly sodic. Severity of the problems associated with high clay and high adsorbed sodium content increase with depth from the original surface. Low organic matter combined with fine texture enhances the sodium dispersion effect which renders the spoil materials extremely unstable, highly impermeable, and erodible to water. Available phosphorus in spoil materials was very low. Available nitrogen varied considerably, depending on the age of the exposed spoils. Treatments showing promise for reclamation include fertilization (especially phosphorus) in combination with the use of topsoil, vegetative (straw) mulches, and possibly gypsum as a calcium amendment. Response to gypsum in field studies has been disappointingly slow. Strip mining is accelerating greatly in the northern Plains; therefore, means must be developed to reduce the textural, sodic, and fertility limitations before appreciable growth and survival of desirable perennial plants can be obtained under the semiarid climate of the region.

Saulmon, R. W. 1973. Snowdrift management can increase water - harvesting yields. J. Soil and Water Cons., Vol. 28 (3), pp. 118-121.

Abstract

A 3-year study of snowdrift management at an open range site in eastern Montana indicated that standard snow fence can effectively induce snowdrifts on water-harvesting catchment basins. Although water loss by evaporation from induced snowdrifts averaged 50 percent, runoff was increased by 4.4 inches during an average winter season.

Schneider, R.P. 1979. Effects of stubble height on soil moisture and N utilzation. Proceed. Manitoba-North Dakota Zero Tillage Workshop. Agricultural Extension Centre, Manitoba Department of Agric., 1129 Queens Ave., Paper No. 4, 8 p.

Abstract

In 1976 a study was initiated in western North Dakota to evaluate the influence of various residue heights on snow retention, soil water and soil temperature. The winter wheat residue was cut to 36, 18 and 0 cm, respectively. Soil moisture determination were made at initation and it was found that there was no soil-plant available water present at that time. Soil temperature information from the soil surface and from two inches in the soil shows that the height of residue significantly reduced soil temperature. The critical soil temperature for winter wheat survival is 4°F. This temperature was reached only in the plots that had no residue left standing. It was also found that as the height of the residue increases, the amount of water retained increases. Residue height and N rate influence yield and protein as well as monetary returns. As the height of residue increased (increased available water) the yield and return due to fertilizer also increased. It was also found that the storage efficiency of water increased when the height of residue increased.

Schmidt, Jr., R.A. 1972. Sublimation of wind-transported snow - a model USDA For. Serv. Res. Rap. RM-90. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. 24 pp.

Abstract

Although a small process in the total hydrologic cycle, sublimation of solid precipitation during redistribution by wind may be a significant part of the water balance in certain regions. The objective of this work is to formulate a mathematical model to estimate the mass of snow that returns to vapor as the air-snow mixture moves downwind over a horizontal snow surface.

Schuman, G.E., Berg, W.A. and Power, J.F. 1976. Management of mine wastes in the Western United States. Land Application of Waste Materials, pp. 181-192.

Abstract

Surface mining in the United States disturbed 3.2 million acres of land by 1965. Approximately 20% of the existing spoils are unable to vegetate because of physical and chemical characteristics. Soil factors such as high soluble salts, high exchangeable sodium and generally lwo fertility make reclamation difficult. Another major limiting factor in the vegetation of these areas is the limited rainfall and short growing season.

Siddoway, F.H. 1970. Barriers for wind erosion control and water conservation. J. Soil and Water Cons., Vol. 25, pp. 180-184.

Abstract

The most familar type of barrier in the Great Plains is the multiple- or single-row planting of trees and shrubs across fields. The benefits of these windbreaks are:

1) Controlling wind erosion to minimize soil loss and to prevent seedling damage from windblown soil.

2) Trapping snow in winter to supply water for subsequent crops.

3) Protecting livestock, roads and farmsteads against harsh northern blizzards and other ill effects of wind.

4) Providing habitat for wildlife.

5) Enhancing the beauty of an otherwise almost treeless landscape.

Skidmore, E.L., Hagen, L.J., Naylor, D.G. and Teare, I.D. 1974. Winter wheat response to barrier induced microclimate. Agron. J., Vol. 66, pp. 501-505.

Abstract

The purpose of this research was to investigate morphological and physiological response of winter wheat (Triticum aestivum L.) to microclimate induced by a slat-fence wind barrier. Six varieties of wheat were grown in 90-m long plots running perpendicular to centrally placed, east-west barriers. Meteorological conditions and plant response were observed on selected days. Stomatal resistance and leaf water potential were measured with stomatal resistance meter and pressure bomb, respectively. Rate of photosynthesis was evaluated by determining uptake of labeled CO_2. When environmental conditions were conducive to plant water stress, the plants in the sheltered area had significantly lower stomatal diffusive resistance, tended to have higher leaf-water potential, and photosynthesized at an equal to significantly greater rate than those in the open field, even though plants in shelter contained 24% less leaf chlorophyll than those in open field. On days when water stress was low, the difference in plant responses between open field and shelter was generally nonsignificant. The plants in the sheltered area generally grew taller, had larger leaves, and had improved water-stress relationships compared with those in open field. Yet, the grain yields were not consistently increased for the growing environment at Manhattan, Kansas.

Smika, D.E. and Whitfield, C.J. 1966. Effect of standing wheat stubble on storage of winter precipitation. J. Soil and Water Cons., Vol. 21, pp. 138-141.

Abstract

Moisture received in the Great Plains in the form of rain or snow is subject to wide annual fluctuation, both in total amount received and distribution within the season. At North Platte, Nebraska, the 58-year averaged annual precipitation is 19.34 inches. Recorded annual precipitation extremes, however, were 34.85 and 11.18 inches.

That portion of the annual precipitation received during the winter months, generally in the form of snow, averages 2.93 inches. This precipitation is derived from an average annual snowfall of 26.6 inches. Although only 15.51 percent of the annual precipitation falls as snow, this precipitation, if properly conserved and utilized, is of major importance to dryland farming.

Studies in Canada showed that 37 percent of winter precipitation was stored when grain stubble was left standing, but only 9 percent was stored when the soil was bare. At Mandan, North Dakota, it was found that a dry surface soil layer will retain more snow moisture than a wet surface soil layer. Studies prior to 1920 at Colby, Kansas, comparing standing wheat stubble following binder harvest with fall plowing, revealed that average winter moisture storage was 71 percent with standing stubble and 33 percent with fall plowing. The short stubble left following binder harvest does not have the snow trapping potential of the taller stubble left by combine harvesting.

Soiseth, R.J., Wight, J.R. and Aase, J.K. 1974. Improvement of panspot (solonetzic) range sites by contour furrowing. J. Range Manage., Vol. 27, pp. 107-110.

Abstract

We studied the effects of 3-, 7-, and 10-year-old contour furrowing on some physical and chemical soil properties of pansport range sites in southeastern Montana. Changes in soil bulk density, and sodium-adsoprtion-ratio (SAR), and salinity (EC) on the contour-furrowed areas were generally small, but a definite ameliorating trend was established. Contour furrowing increased infiltration rates 0.25 to 3.11 cm/hr and increased forage yields 498 to 7700 kg/ha. Reduced SAR and EC on contour furrowed areas were attributed to increased infiltration.

Staple, W.J. and Lehane, J.J. Wheat yield and use of moisture on substations in southern Saskatchewan. Can. J. Agri. Sci., Vol. 34, pp. 460-468.

Abstract

Twelve years' data on the use of moisture by wheat crops at seven Experimental Substations were summarized. The linear regression of yield on evapotranspiration showed an increase of 3.5 bushels per acre for each additional inch of water used by the crop. The relationship was actually curvilinear so that for high evapotranspiration the increase per inch was approximately 6 bushels per acre. These increases resulted not only from the direct benefits of moisture availability, but also from all factors associated with evapotranspiration that were favourable to the crop.

The estimate of yield on the substations was significantly improved when rainfall and stored moisture were used as separate variables. The regression coefficient for rainfall was 1.5 times that for stored mositure. This ratio was greater than that obtained from long-time tank and field experiments at Swift Current.

The total variance in yield was divided into parts due to differences between substations, between seasons and residual variance. After crop yields were adjusted for differences in moisture use on the basis of the residual variance, the remaining differences in yields between substations were just short of significance, and those between seasons were highly significant.

Yields of wheat on fallow were not as highly correlated with total (24 month) precipitation as with evaportranspiration becuase of variability in moisture storage during the 21-month summerfallow period.

Staple, W.J. and Lehane, J.J. 1952. The conservation of soil moisture in Southern Saskatchewan. Scientific Agriculture, Vol. 32, pp. 36-47.

Abstract

Weed control is important in water conservation but fall ploughing can cause lower snow trapping by the stubble. The Noble blade, which leaves the stubble standing and the one-way disk are used to control this problem. The mean conservation of winter precipitation was 1.4 inches in stubble fields and 0.7 inches in summerfallow. Comparison of winter snowcover in stubble and fallow fields are shown.

Staple, W.J. and Lehane, J.J. 1955. The influence of field shelterbelts on wind velocity, evaporation, soil moisture, and crop yield. Can. J. Agri. Sci., Vol. 35, pp. 440-453.

Abstract

Five years' measurements of the influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield are described. It is shown that shelterbelts and hedge rows reduce the velocity of cross-winds to a distance at least 20 times the height of the trees. In this way hedge rows, once established, reduce the hazard of soil drifting. The reduction in evaporation observed near field shelterbelts was small, and from the information available it does not appear likely that it would have a measureable influence on soil moisture conservation or wheat yield.

Snow accumulation near shelterbelts varied from almost nil in years of low snowfall to drifts 70 feet wide in years of ample snowfall and strong winds. These snow drifts increased the soil moisture near the shelters at seeding time, and this in turn resulted in greater yields than obtained in the centre of the fields. The net increase in yield in one group of sheltered fields for the 5-year period, taking into account the area occupied by the trees, was 0.7 bushel per acre. Increased yields due to snow accumulation in shelterbelt projects may occur to the extent that loss of snow to ditches or gullies is prevented or the distribution of the snow is improved.

Staple, W.J., Lehane, J.J. and Wenhardt, A. 1960. Conservation of soil moisture from fall and winter precipitation. Can. J. Soil Sci., Vol. 40, pp. 80-88.

Abstract

Twenty years' results showed that 37 per cent of the over-winter precipitation at Swift Current was conserved in stubble fields and 9 per cent in fallow. Further anlaysis showed that rainfall and snowfall were conserved equally well in stubble but that conservation in fallow was mostly from rainfall. Much of the snow was blown from the fallow and accumulated in the stubble.

Fall moisture was also a factor, in that each inch of moisture stored in the soil in the fall reduced the over-winter conservation by approximately 0.2 inch.

Nine years' results with fall cultivation on stubble showed that one-way disking after harvest reduced the winter storage in 3 years out of 9. Apparently any gain in moisture conservation from the removal of weed growth was more than offset by reduced snow accumulation during the winter. Blade tillage in the fall resulted in greater moisture storage at seed-time in 1 year out of 9.

Stockler, J.H. 1963. Shelterbelts and their effects on crop yields in the Great Plains. J. Soil and Water Conservation, Vol. 18, pp. 139-144.

Abstract

Narrow shelterbelts contribute to soil and water conservation in the Great Plains by reducing wind erosion and evaporation and by increasing soil moisture on fields through trapping of snow. Estimated net yield increases with 4 lineal miles of east-west, 40 foot-high shelterbelts per square mile are 0.67 and 0.87 bushel per acre for small grains and corn respectively. With 8 lineal miles of shelterbelts per square mile these yield increases would be approximately doubled. Crop yield increases resulting from shelterbelts protection are somewhat better in the Dakotas than in Nebraska and Kanses.

Stoeckler, J.H. and Bates, C.G. 1939. Shelterbelts: The advantages of porous soils for trees. J. Forestry, Vol. 37, pp. 205-221.

Abstract

This article treats of the moisture supply available for trees planted in the plains region, with particular reference to the effect of soil quality and porosity upon the storage and availability of whatever precipitation may be received. It attempts to explain by moisture accumulation records obtained in Oklahoma, and other data, the natural tree or shrub growth which frequently is found on sandy soils, in contrast to the "short-grass" characteristics of the finer soils under the same climatic conditions and the much greater difficulties which they present to the tree planter. It closes with a brief description of special moisture - conserving measures which may be necessary for reasonable tree success on the "hard" lands.

Sturges, D.L. 1979. Boundary Ridge snow management project. Unpublished Report on a co-operative snow management project for Poison Creek Grazing Allotment in Wyoming between U.S. Bureau of Land Management and the Rocky Mountain Forest and Range Experiment Station.

Abstract

Twenty-five acres of sagebrush on the windward side of Boundary Ridge were chopped, allowing wind-carried snow to deposit in a lee-drift. Water from the melting of this snowdrift became available to fill a downstream storage reservoir. Winter precipitation (11 November 1978 to 24 March 79) caught in a storage gauge amounted to 6.2 inches and contributed about 1.2 ac-ft directly to the drift. At maximum accumulation the drift contained 5.9 ac-ft of water, including an additional 4.7 ac-ft resulting from the sagebrush treatment.

Sturrock, J.W. 1969. Evaluation of plastic windbreak and glasshouse shading (netlon) in Canterbury, New Zealand. New Zealand J. Agric. Res., Vol. 12, pp 248-255.

Abstract

The windbreak consists of diamond-shaped mesh, approximately 6.4 mm across. A barrier 5 ft high and 100 ft long was erected on a flat, windswept field. A single layer of windbreak effected a maximum smooth, non-turbulent reduction in wind speed of 40% on the lee side. Evaporation was reduced by a maximum of 30%. A folded layer reduced wind by a maximum of 65%, and evaporation was reduced by a maximum of 40%.

Swank, G.W. and Booth, R.W. 1970. Snow fencing to redistribute snow accumulation. J. Soil and Water Cons., Vol. 25, pp. 197-198.

Abstract

Properly placed snow fences can successfully redistribute snow supplies in areas where snow is frequently relocated by strong winds. Application of fence-induced snow redistribution can be a means of more effectively using an existing water resource to meet increasing demands. Induced-drifting by properly located fences can provide a source of water that normally may not be available on the particular site when or where it is needed. The slow release of redistributed snow can supplement streamflow, and impoundments to benefit recreation, fish, wildlife, livestock, and plant growth needs.

Swanson, R.H. and Stevenson, D.R. 1971. Managing Snow accumulation and melt under leafless aspen to enhance watershed value. Proc. 39th Western Snow Conference, Billings, Montana. pp. 63-67.

Abstract

Leafless aspen and willow stands are important in localizing accumulation areas and altering the ablation state. Observational evidence shows that snow under the canopy remains even during chinook periods that removes the total pack from clear areas. Small openings in the leafless canopy of aspen are effective snow traps.

Sturges, D.L. 1977. Snow accumulation and melt in sprayed and undisturbed big sagebrush vegetation. USDA Forest Service Res. Note RM-348. 6 pp.

Abstract

The influence of big sagebrush control on snow accumulation and melt was studied in a location where wind is an important snow relocation agent. A small ($\leq$ 5 cm) but significant reduction in snow accumulation was detected before vegetation was covered by snow on plots sprayed with 2,4-D compared to plots with untreated vegetation.

Sagebrush control had no effect upon maximum depth of snow accumulation or snowmelt rates. Snow deposition at the experimental site was controlled by topographic factors once snow depth exceeded vegetation height.

Tabler, R.D. 1979. Geometry and density of drifts formed by snow fences. Presented at Symposium on Snow in Motion, Aug. 12-17, 1979, Fort Collins, Colorado. Sponsored by the USDA Forest Service and International Glaciology Society.

Abstract

This paper presents results from studies of snowdrifts formed by vertical-slat ("Canadian") and horizontal-slat ("Woming") snow fences having 50% porosity and heights (H) from 0.8 to 3.8 m, on nearly level terrain. Characteristics of equilibrium lee drifts behind the "Wyoming" fence include cross-sectional area $19.3H^2$, length 30H, maximum depth 1.20H, and water-equivalent volume $6.8H^{2.18}$. Upwind drift dimensions include maximum depth 0.5H and length 12H. Drifts behind "Canadian" fences are about 25% smaller than for the "Wyoming" design. Polynomial regression equations are fitted to drift profiles for both fence types. Relationships are presented for the effects of wind orientation and curvature of drifts near fence ends, as well as empirical equations describing pre-equilibrium geometry relative to degree of saturation.

Mean density (ρ) of drift snow having depth y, is given by $\rho = 376 + 158 \log y$.

Tabler, R.D. 1979. Self-similarity of wind profiles in blowing snow allows outdoor modeling. Presented at the Symposium on Snow in Motion, Aug. 12-17, 1979, Fort Collins, Colorado, Sponsored by USDA Forest Service and International Glaciology Society.

Abstract

Drifts formed by snow fences appear to be geometrically scaled over a height range of nearly two order of magnitude. This paper examines natural scaling in terms of commonly accepted similarity criteria. It is hypothesized that requirements for dynamic similarity of flow fields are satisfied over a period of time because surface roughness height (z_o) varies approximately as the square of shear velocity (u_*^2) for saltating flows in air. This is demonstrated by intensive wind profile measurements over snow and ice surfaces. Natural scaling of drifts suggests snow erosion and deposition can be studied with reduce-scale models on smooth surfaces outdoors. The feasibility of this technique is demonstrated by results from 1:30 scale models of 1.8- and 3.8-m snow fences on both level lake ice and irregular terrain constructed from compacted snow.

Tabler, Ronald D. 1973. Evaporation losses of windblown snow and the potential for recovery. Proceed. 41st Annual Meeting Western Snow Conference, Grand Junction, Colorado, pp. 75-79.

Abstract

Snow transport distance (R_m), defined as the average distance a snow particle is carried by the wind before it completely evaporates (sublimates), is shown to be a useful concept for estimating sublimation losses from wind-blown snow. R_m has been found from other studies to range from 3,300 to 4,500 ft at sites between 7,500 and 8,500 ft elevation in southeastern Wyoming.

For wind-swept areas where major natural accumulation areas are spaced at 1, 2, and 3(R_m), it is estimated that 50, 75, and 83% of the relocated snow is evaporated back to the atmosphere during transport.

To demonstrate the potential of snow fences to increase snow storage on wind-swept areas, it is shown that where major natural accumulation areas are spaced at 2, 3, and 4 (R_m), fences spaced at 1(R_m) would be expected to increase total snow accumulation by about 100, 200, and 300%, respectively, for areas where all precipitation is relocated by the wind.

Tabler, R.D. and Schmidt, Jr., R.A. 1972. Weather conditions that determine snow transport distances at a site in Wyoming. UNESCO/WMO/IAHS Int. Symp. of role of Snow and Ice in Hydrolo. Proceed. Banff, Alberta. Sept. 6, 1972. Vol. 1, pp. 118-127.

Abstract

The design of snow fence systems, either to control blowing and drifting snow on highways or to increase water yield from wind-swept areas, requires an estimate of the amount of blowing snow at the fence site. One proposed method requires the average distance of snow transport, $\bar{R}_m$, defined as the distance the average sized snow particle will be transported before it completely sublimates. Schmidt has recently published a mathematical model for sublimation rate which can be used to calculate this transport distance if particle size and speed, air temperature and relative humidity, and totàl isolation are known.

Tabler, R.D. and Schmidt, Jr., R.A. 1972. Weather conditions that determine snow transport distances at a site in Wyoming. UNESCO/WMO/IAHS Int. Symp. of role of Snow and Ice in Hydrolo. Proceed. Banff, Alberta. Sept. 6, 1972. Vol. 1, pp. 118-127.

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Tabler, R.D. 1968. Physical and economic design criteria for induced snow accumulation projects. Water Resources Res., Vol. 4, pp. 513-519.

Abstract

Snow fencing promises to be an important means of increasing surface water yield or ground water recharge on windswept watersheds where snow is an important form of precipitation. Assuming an equally spaced series of snow fences, a physical production function can be developed that relates fence spacing to the 'most probable' annual snow catch, based on a probability of winter precipitation. The optimum scale of development in terms of fence spacing, determined by standard marginal analysis, indicates that the smaller the marginal value of output with respect to inputs, the great the probability must be of the fences filling annually if net benefits are to be maximized.

Tabler, R.D. and Johnson, K.L. 1971. Snow fences for watershed Management. Proc. Snow and Ice in Relation to Wildlife and Recreation Symp. Ames, Iowa. pp. 116-121.

Abstract

Snow fences hold promise on the windswept high plains for reducing sublimation losses of wind-blown snow, as a water diversion technique, and to make subsequent snowpack management feasible. A comparison of two adjacent drainages in southeast Wyoming suggested that differences in water yield and timing might be attributed to the relative abundance of barriers trapping wind-blown snow.

After 9 years of pretreatment measurements on three small experimental watersheds, a snow fence was built on one in 1969. Although more years will be required to determine the effects of the treatment on water yield and snow accumulation, first-year results show the snow fence increased peak snowpack by 70%.

Tabler, R.D. 1974. New engineering criteria for snow fence systems. Transp. Res. Board Record 506, NRC Transp. Res. Council. pp. 65-78.

Abstract

New engineering criteria for snow fences have been used to design a snow control system that is unusally effective in preventing drifts, improving visibility, and reducing the formation of road ice. This paper describes these criteria and the research results on which they are based. The amount of blowing snow arriving at each site was estimated from an equation relating the snow transfer coefficient, the transport distance, and the precipitation received over the contributing distance. Measurements in southeast Wyoming show the "equivalent transport distance" to range from about 500 to 1200 m. The height and number of rows of fencing at each site were selected to provide the required capacity. An equation for computing the cross-sectional area of the saturated lee drift behind the new Wyoming Highway Department standard-plan fence is given. Tall (3.8-m) fences have been used in preference to shorter onces because experience has shown taller structures to be more efficient in trapping snow and to have a much lower construction cost per unit of storage. Because studies have shown the average trapping efficiency of a fence from onset of accumulation to times of saturation to be about 85 percent, storage capacity is made about 20 percent greater than the estimated amount of blowing snow. Terrain can be used to greatly increase the capacity of snow fences; for example, capacity is increased 15-20 percent for each 0.017 rad of downslope behind a fence and about 15 percent for each 0.017 rad of upslope in the approach zone. Because wind sweeping around fence ends reduces storage capacity significantly over a distance from the ends of 12 times the height, length of fences should be at least 30 times their height and staggered barriers should be overlapped at least 8 times their height.

Tabler, R.D. 1973. Evaporation losses of windblown snow and potential for recovery. 41st Western Snow Conference, Grand Junction, Colorado. April 17-19, 1973. pp. 572-73.

Abstract

A recent mathematical model demonstrates a previously unrecognized potential for significant evaporation (sublimation) from snow particles during their transport by wind. Our studies with snow fences in Wyoming also have indicated large sublimation losses from wind-blown snow. This paper provides evidence supporting a method we used to estimate annual sublimation amounts, and demonstrates the magnitude of these losses from extensive wind-swept areas.

Tabler, R.D. and Veal, D.L. 1971. Effect of snow fence height on wind speed. Bulletin of the Int. Assoc. of Scientific Hydrology, Vol. XVI (4). pp. 49-56.

Abstract

Accumulations of snow behind fences may increase the water yield in windswept areas. The efficiency of snow collection depends on the reduction in wind speed in the lee of the fence. Wind speeds have been measured to windward and to leeward of vertical slat fences from 6 to 16 ft. high. The down-wind measurements were made at distances of 2.5H, 5H and 10H from the fence where H is the height of the fence. Speed measurements at various levels were integrated up to the height of the fence and the percentage in windspeed was calculated. Expressions are given for the velocity reduction factor at distances down-wind of fences having a bottom gap, and for the cross-sectional area of a fully developed drift.

Tabler, R.D. 1971. Design of a Watershed snow fence system, and first-year snow accumulation. Proc. 39th Western Snow Conference, Billings, Montana, Apr. 1971, pp. 50-55.

Abstract

Inducing snow accumulation with fences in areas with insufficient natural barriers can materially increase total snow storage by reducing sublimative "losses" and by diverting snow that would be transported further downwind. Snow fences provide a unique means of redistributing water on a drainage by concentrating snow in a relatively few large accumulations rather than in numerous smaller drifts. Snow can be stored at the best locations to improve either on-site use or water yield downstream. The reduced surface area/volume ratio potentially reduces evaporation losses and prolongs the melt period, and improves feasibility of subsequent management for evaporation reduction or melt rate regulation by means of surface additives.

Theakston, F.H. 1962. Snow accumulation about farm structures. Ag. Engr. Soc. of Canada, Vol. 43, pp. 139.

Abstract

This study involves three major objectives as follows:

1) Snow accumulation around buildings.
2) Form factors or roof shapes which aggrevate wind and snow conditions.
3) Windbreaks with relation to design and placement for best results.

To lessen the accumulation of snow around buildings certain recommendations should be followed:

1) Open-front buildings tend to create suction pressures which cause snow to swirl to the interior decreasing usable space for lounging and feeding.
2) Snow accumulates excessively on the lee side of buildings and accessory equipment.
3) Snow particles will fall out of turbulent sections where the wind velocity approaches zero.
4) In long, open-front buildings that is, over 50 ft in length, snow accumulates in the corners of the structure and drafts occur through circulating wind. Partitions at third points in the length of the buildings eliminate some of the poor conditions.
5) Snow fences and windbreaks may often have detrimental effects on structures if improperly located in the farmstead plan.
6) Definite indications of snow accumulation can be determined by model studies prior to construction.

Thorpe, A.D. and Mason, B.J. 1966. The evaporation of ice spheres and ice crystals. British J. Appl. Phys., Vol. 17, pp. 541-548.

Abstract

The rates of evaporation of ice spheres, 0.3-1.8 mm radius, have been measured by direct weighing in air streams of 25-100 cm sec^{-1} at $-3^{o}C$ and $-12^{o}C$ and over a range of Reynolds numbers of 10-200. The experimental results may be represented in terms of heat and transfer coefficients of the form

$$(Nu) = 1.88 + 0.66\ (Pr)^{1/3}\ (Re)^{1/2}$$

and

$$(Sh) = 1.88 + 0.66\ (Sc)^{1/2}\ (Re)^{1/2}$$

where (Nu), (Pr), (Sh), (Sc) and (Re) are respectively the Nusselt, Prandtl, Sherwood, Schmidt and Reynolds numbers, provided that the diffusion coefficients of water vapour in air are about 7% lower than those given in the International Critical Tables. These results are consistent with those quoted by some other workers for evaporating water drops.

Some measurements on snow crystals in the form of hexagonal plates and dendritic stellar crystals reveal the influence of geometrical shape on their rates of evaporation.

Thysell, J.C. 1938. Conservation and use of soil moisture at Mandan, North Dakota, USDA Tech. Bull. 617. 40 pp.

Abstract

In regions of limited rainfall the conservation and use of precipitation in the form of soil moisture has been regarded as one of the most important phases of the problem of crop production. Soil moisture may be conserved through timely tillage, the use of intertilled crops by means of fallow or through protection from surface evaporation and run-off by plants and plant residue on the surface. It is lost through plant transpiration, surface evaporation, run-off and occassionally through seepage. The extent to which precipitation may be conserved in the soil is dependent largely on the character and amount of precipitation and on the character and surface condition of the soil. In this report there is much information on the conservation of water during summer and winter. It shows the differences in the comparative use of spring wheat and other crops and it also shows the importance of stubble cover during certain periods in the year.

Toy, T.J. 1979. Potential evapotranspiration and surface-mine rehabilitation in the Powder River Basin, Wyoming and Montana. J. of Range Manage., Vol. 32(4), pp. 312-316.

Abstract

Energy resource development in the Western United States must contend with the problem of water deficiency resulting from potential evapotranspiration rates which usually exceed precipitation rates. In this report the Blaney-Criddle method, with locally calibrated monthly natural vegetation coefficients, was used to estimate potential evapotranspiration (PET) for the Powder River Basin, Wyoming and Montana. In this area PET ranges from 15.02 inches per year to 26.76 inches. A radiation-based method for microclimatic adjustment of PET is presented. According to inclination at 44^{o} North latitude. annual PET is 17% less on northerly-facing slopes than a horizontal surface and 14% more on southerly-facing slopes.

Unger, P.W., Allen, R.R. and Wiese, A.F. 1971. Tillage and herbicides for surface residue maintenance, weed control and water conservation. J. Soil and Water Cons., Vol. 26, pp. 147-150.

Abstract

A study was conducted to determine the effectiveness of tillage and herbicides for maintaining residues, controlling weeds and volunteer wheat, and storing precipitation as soil water during the period from wheat (Triticum aestivum L.) harvest to gain sorghum bicolor (L.) Moench) planting in an irrigated wheat-sorghum-fallow cropping sequence. About 10,000 pounds of residue per acre were present in July at the beginning of the study. The following spring, surface residues ranged from less than 200 to 4,100 pounds per acre; weed control ranged from 44 to 100 percent; and the increase in available soil water ranged from 2.0 to 5.6 inches. The greater increase in soil water storage resulting from maintaining residues at the surface suggests a tremendous potential for storing precipitation for later plant use. The added soil water stored by the herbicide treatments compared with the tandem disk treatment nearly equaled that stored by preplant irrigations.

University of Saskathcewan, Extension Division (Edit.). 1978. Guide to farm practise in Saskatchewan, 1978. Sask. Agri. Services Coordinating Comm. Canada and Sask. Depts. of Agric. Modern Press. Saskatoon, Sask. 199 p.

Abstract

Snowfall may be managed to increase useful water supplies. Snow readily blows off exposed areas to accumulate in gullies or near obstacles which disturb the wind. By strategically locating fencing, equipment, or hedges, snow can be made to accumulate over a dugout or its drainage area, thereby increasing surface-water supplies. The same principle may be applied to keep feedlots, roads, and working areas relatively free form snow.

Snow accumulation on fields may be increased by maintaining stubble or a cover or catch crop, and possibly by plowing or windrowing the snow. Shelterbelts are also effective in retaining the snow cover and in extending the melting period.

U.S. National Academy of Sciences. 1970. Snow research and control. Appendix C in Polar Research - A Survey, pp. 97-102.

Abstract

Snow farms a transient sedimentary veneer on much of the earth's land surfaces. The diverse economic effects of this snow layer are incalcuable . It is a major and renewable hydraulic reservoir; in many areas of North American more than half of the utilized water is derived from melted winter snow. Very few investigators have concerned themselves with research on the properties of snow. The purposeful interference by man with the natural character of winter snow, either by modifying its deposition or by altering its postdepositial character, eg, by such activities as snow drift control with fences, erection of structures to inhibit avalanches, or selective forest cutting to improve snow storage, is relatively minor. Snow influences a broad area of geophiscal phenomena - it stores water, modifies surface albedo, insulates the ground, and modified plant and animal habitats.

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Abstract

Snow farms a transient sedimentary veneer on much of the earth's land surfaces. The diverse economic effects of this snow layer are incalcuable . It is a major and renewable hydraulic reservoir; in many areas of North American more than half of the utilized water is derived from melted winter snow. Very few investigators have concerned themselves with research on the properties of snow. The purposeful interference by man with the natural character of winter snow, either by modifying its deposition or by altering its postdeposital character, eg, by such activities as snow drift control with fences, erection of structures to inhibit avalanches, or selective forest cutting to improve snow storage, is relatively minor. Snow influences a broad area of geophiscal phenomena - it stores water, modifies surface albedo, insulates the ground, and modified plant and animal habitats.

Van Haveren; B.P. and W.D. Striffler. 1976. Snowmelt recharge on a shortgrass prairie site. Proceed. 44th Annual Meeting Western Snow Conference. April 20-22. Calgary, Alberta, pp. 56-62.

Abstract

An analysis was made of the contribution of winter precipitation to soil water recharge for the 1970-71 winter period on the IBP Pawnee Site in northeastern Colorado.

Winter storm characteristics for 1970-71 were analyzed and compared with longer term records of snowfall events in the region.

Soil water recharge was inferred from periodic measurements of soil water content with a neutron probe at 60 sampling locations. The sampling design included three grazing treatments, five levels of position-on-slope, and two slope orientations. Assuming minimal evapotranspiration losses from the soil, net soil water recharge was computed for each of the 60 sites for the winter period by summing the differences between soil water content measurements taken between September 1970 and March 1971.

Indices expressing the importance of snowmelt recharge to total soil water recharge (the "snowmelt recharge ratio"), and the importance of snowmelt recharge to winter precipitation (the "snowmelt recharge efficiency"), were computed and analyzed for treatment effects.

Despite its minor contribution to the total annual precipitation on the shortgrass prairie, snowmelt appears to be an important hydrologic input to the soil water budget.

Wight, J.R., Neff, E.L. and Siddoway, F.H. 1975. Snow management on eastern Montana rangelands. In Snow Management on the Great Plains. Great Plains Agr. Coun. Pub. No. 73. Lincoln, Nebraska. pp. 138-143.

Abstract

Snow in the Northern Great Plains is a vest but unmanaged resource. The amount of water available from properly managed snow could mean the difference between an adequate and inadequate forage supply on native rangelands. Surface modifications such as contour furrowing and level benches have given promising results for snow management as have forage residues, vegetational barriers and artificial barriers. However, there are several processes in snow management that need better understanding such as the evaporation from a snowpack and the infiltration of snow water into frozen or partially frozen soils.

Wight, J.R. and Siddoway, F.H. 1972. Improving precipitation-use efficiency on rangeland by surface modification. J. Soil and Water Cons., Vol. 27, pp. 170-174.

Abstract

Five surface modification treatments-contour furrowing, pitting, scalping, miniature fallowing, and rotary subsoiling-were evaluated for their effect on precipitation-use effiency (PUE) on rangelands in the Northern Plains. Contour furrowing, scalping, pitting, and miniature fallowing (fallow strips were allowed to revegetate) increased PUE. Improved PUE resulted from changes in soil water, species composition, and soil fertility which accompanied the surface-modification treatments. Soil-water benefits resulted primarily from increased retention of runoff and snow. On sites with low infiltration capacities, surface modification increased PUE more than 100 percent. On sites with high infiltration capacities, PUE increased about 20 percent, mainly because of changes in species composition and increases in nutrient availability.

Wight, J.R. and White, L.M. 1974. Interseeding and pitting on a sandy range site in Eastern Montana. J. Range Manage., Vol. 27 (3), pp. 206-210.

Abstract

A study of the effects of interseeding and pitting on herbage yield, species composition, soil water content, and nitrogen uptake was conducted on a sandy range site in eastern Montana from 1967 to 1972. Over these 6 years, interseeding with a lister and rotary tiller increased perennial grass yields 30 and 24%, respectively. Pitting increased the yield of sedges (Carex spp.) over most of the 6 years, but increased total grass yield only in 1969. The yield increase from interseeding was due to increased growth of native western wheatgrass (Agropyron smithii) and interseeded species. An interseeded mixture of western wheatgrass, bluebunch wheatgrass (Aspicatum), green needlegrass (Stipa viridual), and little bluestem (Andropogon scoparius) produced two to three times more than any individual species. Interseeding by lister and rotary tiller increased perennial grass yields in the sixth year after treatment by 58 and 41%, respectively, indicating potential long-term benefits from interseeding. Of the treatments, only lister interseeding showed evidence of increasing soil water recharge on this sandy range site. Tillage associated with the interseeding and pitting treatments increased the uptake of nitrogen by plants for at least 2 years after treatment.

Wight, J.R., Neff, E.L. and Soiseth, R.J. 1978. Vegetation response to contour furrowing. J. Range Manage., Vol 31 (2), pp. 97-101.

Abstract

Over an 8-year period, contour furrowing on a panspot range site increased average annual herbage production 165% (527 kg/ha), increased plant available soil water 107%, and reduced total basal cover 73% (from 15.72 to 4.22%). On a saline-upland site, contour furrowing increased available water but had no measurable effect on total herbage production and basal cover. Thickspike and western wheatgrass accounted for most of the increased yields on the contour-furrowed panspot site. High yields on the furrowed plots were due primarily to increased soil water resulting from increased over-winter recharge and reduced summer runoff.

Willis, W.O. and Carlson, C.W. 1961. Winter precipitation-too much is lost. North Dakota Farm Res. Bimo, Bull., Vol. 22, pp. 14-15.

Abstract

Thirty-seven percent of winter precipitation is retained in the soil when covered with stubble. The moisture retained in bare fallow is less than 10%. Soil that is wet in the fall freezes slower and not as deep as soil that is dry in the fall. Runoff from a dry soil is likely to be less than wet soil. However, a dry soil did not retain enough water from the snowpack to bring it up to that of soil which had been wet in the fall to a depth of 4 feet. Measurements of spring runoff showed that fall moisture conditions of the surface foot of soil govern the amount of runoff.

Willis, W.O. and Carlson, C.W. 1962. Conservation of winter precipitation in the Northern Plains. J. Soil and Water Cons., Vol. 17, pp. 122-123.

Abstract

A large percentage of the moisture in the winter snow-pack is usually lost in the form of runoff during the spring thaw. The winter loss due to runoff not only limits crop production but can also be a major cause of floods. Moisture conditions in the top 12 inches of the soil prior to snowfall may have consierable influence on the snow-pack moisture retained by the soil. Soil that is dry in the fall will cause less runoff in the spring but the gain in soil moisture is not sufficient enough to bring the moisture level to that of soil that is not allowed to dry in the fall. Thus, attempts to increase storage of winter precipitation by maintaining the soil in a dry condition in the fall may not be advantageous.

Willis, W.O., Haas, H.J. and Carlson, C.W. 1969. Snowpack runoff as affected by stubble height. Soil Sci., Vol. 107 (4), pp. 256-269.

Abstract

Snowfall constitutes 2 to 3.5 inches (about 20 per cent) of the annual precipitation in the semiarid northern Great Plains. Adding one inch of water above a precipitation base of 8 to 10 inches can increase spring wheat yields by three or more bushels per acre. In some cases it is conceivable that as little as 0.5 inches of soil water may provide the margin between a poor and a good crop yield. Thus, in the northern plains, it is important to manage the snowpack for maximum water conservation.

Previous work shows that the soil water level at freezing in the fall affects depth, of frost and amount of snowpack runoff in the spring. It is well known that grain stubble left standing after harvest effectively traps snow. It is also well known that snow insulates soil against changes in soil temperature. The objective of the following study was to determine the influence of stubble height on behavior of snowpack runoff, and subsequent changes in soil water content.

Willis, W.O. 1975. Soil water, management, and other factors that affect crop production. IAEA No. 192, pp. 1-17.

Abstract

Soil water gained through managing precipitation is the key to dryland crop or range production. The effects of various water conservation practises, such as the use of level benches, summerfallow, tillage type, depth and timing, and mulching are discussed.

Willis, W.O., Carlson, C.W., Alessi, J. and Haas, H.J. 1961. Depth of freezing and spring run-off as related to fall soil-moisture level. Can. J. of Soil Sci., Vol. 41. pp. 115-123.

Abstract

Studies were conducted at Mandan, North Dakota, to evaluate effects of soil moisture level in the fall and snow depth on depth of freezing and spring run-off. Results showed that soil which was dry in the fall froze faster and deeper than a wet soil. Insulative effects of snow increased with snow depth. In the spring, a dry profile thawed upward to the surface while a wet soil thawed both upward and downward from the soil surface. Run-off in the spring was less from dry soil. Completion of run-off coincided with frost removal from the dry plots but thawing was not complete in the wet soil until about 10 days after run-off had ceased. Time of run-off completion was the same for wet or dry soils.

Willis, W.O. and Haas, H.J. 1969. Water conservation overwinter in the Great Plains. J. Soil and Water Cons., Vol. 24, pp. 184-186.

Abstract

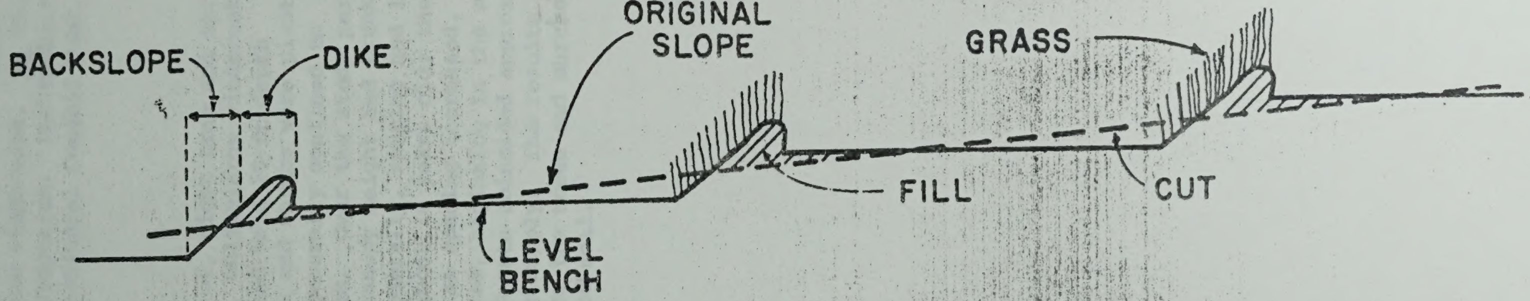
If the snow is held where it falls and if the soil is dry in the fall before freezing, spring runoff amounts to about 50 percent of the snowpack; if the soil is wet in the fall before freezing, about 80 percent of the snowpack runs off. Runoff also increases with increased stubble height but fall soil water content affects runoff more than does stubble height. Stubble height also effects the initiation of snowmelts. The taller the stubble, the earlier the snowmelt begins.

An effective method of both trapping and holding snowmelt in place until the water infiltrates is the level bench. Other effective snow trapping techniques include the the use of tree shelterbelts, or rows of annual plants. Each inch of water added to the minimum quantity required for plant growth and grain production can increase wheat yields 3 bushels per acre or more.

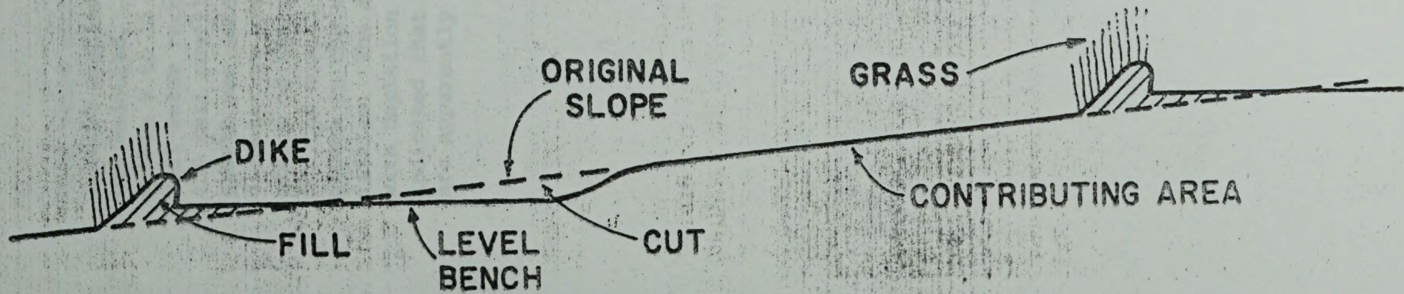
Willis, W.O. and H.J. Haas. 1971. Snow and snowmelt management with level benches, small grain stubble and windbreaks. Proceed. Snow and Ice in Relation to Wildlife and Recreation Symposium. Ames, Iowa. pp. 86-95.

Abstract

Successful dryland farming is highly dependent on good water conservation practises. Snow is a source of water which is not presently fully utilized in the Northern Great Plains. The problem is two-fold: one is to trap and hold the snow in a place where it is wanted, the other is to hold the snowmelt in place until it can infiltrate the soil. Level benches and stubble-stripping have both been shown to be successful management practises. The diagrams on the following pages show the advantages of using these management techniques.



LEVEL BENCHES WITHOUT CONTRIBUTING AREA



LEVEL BENCH WITH CONTRIBUTING AREA

Diagrammatic cross-section of level [illegible] without and with contributing area.

Willis, W.O., Frank, A.B., George, E.J., and Haas. H.J. 1976. Soil water extraction by, and growth of multi-row windbreaks. In Richard W. Tinus (ed). Proceedings of the Symposium: Shelterbelts on the Great Plains. Great Plains Agricultural Council Publ. No. 78. pp. 87-92.

Abstract

Soil water extracted by, and growth of, eight tree and shrub species planted in variously spaced, multiplerow windbreaks was measured. Soil water was depleted to a 10-ft depth within 9 to 11 years after the trees and shrubs were plants. Soil water recharge overwinter was generally confined to the soil profile above the 4-ft depth. Over the study period, growth was determined by measuring canopy height and trunk diameter at breast height (DBH). Generally, spacing had little effect on DBH until the trees were about 10 years old; then, for the next 5 years, DBH increased as spacing increased. Rate of growth in DBH slowed, for most species, beginning in the mid-fifties. The decrease in DBH-growth rate coincided approxiately with depletion of initial soil water supply. The results indicated that the bulk of roots, for the trees and shrubs tested, are apparently in the surface 4 ft of soil.

Willis, W.O. 1978. Snow on the Great Plains. Proceed. Meeting on Modeling of Snow Cover Runoff (SC. Colbeck and M. Ray, Editors) U.S. Army Corps of Engineers, CRREL, Am. Geophyscial Union, and Am. Meteorological Society, pp. 56-62.

Abstract

Snow is an important source of water for dryland crops and range plants in the central and northern Great Plains. Best management of snow to increase soil water for plant use requires trapping and holding the snow where it is needed, and holding the snowmelt in place until it infiltrates. The subsequent gains in soil water may increase wheat yield by about 70 to 160 kg/ha or native range forage yield by about 150 kg/ha for each centimeter of soil water stored and used.

Single-row tree windbreaks, grass barriers, standing grain stubble, rows of sorghum or sudangrass stalks on cropland, and shrubs) on rangeland have proved effective for managing the snowpack. Level benches and some terraces have proved effective for trapping snow and holding snowmelt. Runoff of snowmelt plus evaporation can be 50 to 100% of the snowpack in the northern Plains region, depending on antecedent soil water conditions in the fall before freezing and weather conditions during spring thaw. Generally, there is essentially no snowmelt runoff from cropland in the central Plains.

Wilson, T.I. 1961. Stripcropping Pacific Northwest grainlands. J. Soil and Water Cons., Vol. 16, pp. 25-27.

Abstract

Stripcropping is a practise which gives maximum protection from wind and water erosion on cultivated lands. The land is broken up into strips across the slope or at right angles to prevailing winds so that only a narrow strip of land is open to erosion at any one time. It is most effective when used with a complete conservation program of stubble, mulch, rough tillage, contouring, grass-legume rotations and effective water disposal practises.

There are 4 types of stripcropping:

1) Wind stripcropping - Wind strips are uniform in width, usually straight, and laid out as nearly as possible at right angles to prevailing winds. Widths are about 120-240 feet.

2) Contour stripcropping - Contour strips are at right angles to the natural slope of the land.

3) Field stripcropping - Field stripcropping is similar to wind stripcropping except that uniform strips are placed at right angles to the general slope of the land rather than at right angles to the wind.

4) Buffer stripcropping - Buffer strip of grass or grass-legume mixtures are laid out between strips of crops in regular rotations.

Stripcropping also provides a buffer that catches snow blown from an exposed strip to increase moisture for subsequent crops.

Woodruff, N.P. 1954. Shelterbelt and surface barrier effects on wind velocities, evaporation, house heating, and snowdrifting. Kansas Agric. Exp. Stn. Tech. Bull. 77, Kansas State College, Manhattan, Kansas.

Abstract

Models of shelterbelts, snow fences, and solid walls were tested in a wind tunnel to determine their effects on wind velocities, evaporation rates, snowdrifting, and house heating. Velocity patterns obtained in the vicinity of full-scale snow fences under atmosphereic conditions also are presented to show the agreement between studies of the problem with wind tunnels and under field conditions.

The comparative velocity pattern about the single and successive snow fences indicates that wind tunnel approaches can be used to make reasonable estimates of the effects of full-scale surface barriers.

The snow fence surface barrier was shown to gave the following effects on wind velocities:

1. The most substantial reductions in average velocity for a single fence occur in the zone extending from approximately 4 to 10 H. There is also a reduction in wind velocity of at least 20 percent extending a distance of 20 H aft of the single fence.

2. Successive fence data indicate that 4 fences are not sufficient to create an accumulative effect aft of the leeward fences, but reductions of at least 30 percent aft of each fence are obtained with the 15 H spacing used in this experiment.

Horizontal velocity measurements indicate a 5- to 6-H advantage for the leaved shelterbelt and the solid wall over the defoliated belt, as measured by ability to create 25 and 50 percent velocity reductions. The solid wall is also more effective than either of the two shelter-belts in creating 75, 50, and 25 percent velocity reductions. However, both the leaved belt and the solid wall cause a greater upward diversion of the flow lines in the zone above the barrier, resulting in increased eddy formation.

Zaylsie, J.J. 1967. Modified windbreaks control wind, snow drift. North Dakota Farm Res., Vol. 24 (9), pp. 4-6.

Abstract

In the fall of 1965, 20 Siberian elm single row plantings of 300 feet long and 12 to 18 feet tall, had sections of the lower crown modified by pruning. Each section was followed by a 300 foot check strip of unpruned trees. During the winter, periodic snow depth measurements were taken perpendicular to and at 10 foot intervals on both the wind and leeward side of the pruned plots and the check plots. The pruned trees gave a snow drift that was longer and shallower than the unpruned trees. Unpruned trees are tooeffective in trapping snow and holding snow immediately adjacent to the tree row.

The drifts around the unpruned trees provided a more uniform distribution of moisture over the field.

Additional Publications

1. Black, A.L., Siddoway, F.H. and Saulmon, R.W. 1971. Wheatgrass barriers stop soil blowing, trap water. Montana Farmer-Stockman 58(16). pp. 6, 8, 10.

2. Black, A.L. and Reitz, L.L. 1979. Excellent potential: Grasses grown in contour rows. Montana Farmer-Stockman, 57 (16), pp. 36, 38, 40.

3. Brown P.L. and Miller, M.R. 1978. Soil and crop management practises to control saline seeps in the U.S. northern plains. Proc. Dryland Saline Seep Control Meeting. Soil Sci. Congr., Edmonton, Alberta.

4. Greb, B.W. 1978. Tall wheatgrass barriers boosts continuously cropped forage yields. Colorado State University Experiment Station PR 78-16, Fort Collins, Colorado, 3 p.

5. Greb, B.W. and Black, A.L. 1971. Vegetative barriers and artificial fences for managing snow in the central and northern plains. In Arnold O. Haugen (ed.) Proc. Snow and Ice in Relation to Wildlife and Recreation Symposium. Iowa Coop. Wildlife Research Unit, Iowa State University, Ames, Iowa. pp. 96-111.

6. Siddoway, F.H. 1968. Annual and perenial barriers in relation to wind erosion and moisture conservation. Workshop Proceedings - Conservation Tillage in the Great Plains, Great Plains Agricultural Council Pub. No. 32. pp. 145-154.

7. Siddoway, F.H. 1969. Barriers for moisture conservation and wind erosion control in the Great Plains. In Proc. 24th Annual Meeting on SCSA, Aug. 1969, Colorado State University, Fort Collins. pp. 62-66.

8. Siddoway, F.H. and Barnett, A.P. 1976. Water and wind erosion controls aspects of multiple cropping. In Multiple Cropping, ASA Special Pub. # 67. Amer. Soc. Agron. Inc., Madison, Wisc. pp. 317-335.

9. Snyder, J.R. and Skold, M.D. 1978. The economics of snow management. Presented at the 1978 Western Agricultural Economics Association Meeting in Bozeman, Montana, published in the Western Agricultural Economics Journal.

10. Skidmore, E.L. and Siddoway, F.H. 1978. Crop residue requirements to control wind erosion. Crop Residue Management Systems Publ. No. 31.

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17	139	SHELTERBELT	
18	429	SHELTERBELTS	
19	100	17 AND 18	
20	9	1 AND 19	
21	1	SNOW (W) TRAPPING	
22	0	SNOW (W) COLLECTION	
23	0	SNOW (W) UTILIZATION	
24	0	SNOW UTILIZATION	
25	0	SNOW (W) CONSERVATION	
26	37	SNOW (W) ACCUMULATION	
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LITERATURE

l.c. Aase, J.K., and Siddoway, F.H. 1974. Winter microclimate effects on "No-till" winter wheat development as affected by three stubble heights. Agron. Abstracts ~~68:117.~~ Vol. 68, 117 p.

Aase, J.K., Siddoway, F.H., and Black, A.L. 1978. Wheat crown-depth temperatures versus snow depth. Agron. Abstracts ~~70:176.~~ Vol. 70, 176 p.

tr. ② ~~Aase, J.K., and Siddoway, F.H.~~ 1979. Stubble height effects on seasonal microclimate, water balance, and plant development of no-till winter wheat. Agric. Meteorol. Vol. 20. pages?

① ~~Aase, J.K., and Siddoway, F.H.~~ 1979. Crown-depth soil temperatures and winter protection for winter wheat survival. Soil Sci. Soc. Am. J., Vol. 43. pages?

Anderson, H.W. 1972. Forest and Meteorological Influences on Snow and Snowmelt Water and Their Management. ~~Ref.:~~ In: Proceedings ~~of the~~ joint PAO/USSR International Symp. on Forest influences and watershed management, Moscow, U.S.S.R. 1970. pp. 41-54. underline

l.c. Antonov. E.V., and Vasil'ev, G.I. 1978. The Role of Crop Field Shelterbelts in the accumulation and distribution of snow. pp. 89-99.

sp. Aull, J.S., and Ffolliott, P.F. 1975. Measuring Snow Cover from Erts Imagery on The Black River Basin. ~~Ref.:~~ In: Vol. 5; Hydro and Water Resources in Arizona and the Southwest, Proceedings ~~of the~~ 1975 meetings of the Arizona Section, Amer. Water Resources Assoc. and the Hydrology Section, Arizona Acad. of Sci. pp. 215-219. caps

sp. Barnes, A.H. 1970. Photogrammetric Determination of Relative Snow Area. ~~Ref.:~~ U.S. Forrest Service, Rocky Mountain Forest and Range Experiment Station. p. 14, 3 Fig., 3 Tab. l.c.

tr. Benson, C., and Holmgren, B. 1974. Physical characteristics of seasonal snow cover in northern Alaska. Proceedings, Western Snow Conference. pp. 58-63. where held?

Bauer, A., and Zubriski, J.D. 1978. Hard Red Spring Wheat Straw Yields in Relation to Grain Yields. Soil Sci. Soc. Am. J. ~~42:777-781.~~ Vol. 42, p. 777-781. l.c.

l.c. Black, A.L., and Siddoway, F.H. 1977. Winter Wheat Recropping on Dryland as Affected by Stubble Height and Nitrogen Fertilization. Soil Sci. Soc. Am. J. ~~41(6):1186-1190.~~ Vol. 41, No. 6, p. 1186-1190.

l.c. Chang, A.T.C., Shiue, J.C., Boyne, H., and Ellerbruch, D. 1978. Preliminary Results of Passive Microwave Snow Experiment During February and March 1978. ~~Ref.:~~ Available from the Nat. Tech. Info. Service, Springfield, VA 22161 as N79-19519. p. 113.

sp. Cox, L.M., and Zuzel, J.F. 1977. Can Snowdrift Management Really Provide More Summer Water. Portland, Or., The Society. ~~Soc.~~ of Range Management. p. 21. l.c.

Crook, A.G. 1977. Snotel: Monitoring Climatic Factors to Predict Water Supplies. Ref.: J. of Soil and Water Conservation, Vol. 32, No. 6, pp. 294-295.

Davis, R.J. 1972. United States and Mexico: Weather Technology Water Resources and International Law. Ref.: In: Nat. Resources Journal, Vol. 12, No. 4, pp. 530-44.

Davis, R.J. 1978. Weather Modification Law and the Environmental Effects of Snowpack Enhancement (National Environmental Policy Act). Carson City, Proceedings Western Snow Conference. pp. 41-41.

Dobrolenskii, G.A., and Landin, V.P. 1978. Meliorative Effects of Forest Tree Plantings for Erosion Control in Winters with Little Snow (on the Desna River Upland in the Polesye). Kiev, "Urozhai". pp. 45-51.

Essington, E.H., Forslow, E.J., and Tuttle, J.D. 1967. Snow-water Conservation, Part 1; Migration of Evaporation Surpressants Applied To Snow. Publ. Nat. Tech. Info. Serv. p. 89.

Evans, W.E. 1974. Progress in Measuring Snow Cover from ERTS (Earth Resources Technology Satellite) imagery (Remote Sensing). Carson City. Proceedings Western Snow Conference. p. 37-45.

Farnes, P.E., and Shafer, B.A. Summary of Snow Survey Measurements for Montana, 1922-1974. p. 220.

Ffolliott, P.F., and Throud, D.B. A Technique to Evaluate Snowpack Profiles in and Adjacent to Forest Openings. Ref.: In: Hyrdrology and Water Resources in Arizona and the Southwest, Vol. 4., Proceedings of the 1974 Meetings of the AWRA, Arizona Section and The AAS Hydrology Section, Flagstaff, Arizona, pp. 10-17.

Ffolliott, P.F., and Thorud, D.B. 1974. Development of Forest Management Guidelines for Increasing Snowpack Water Yields in Arizona. Ref.: Arizona Water Resources Project Inform., Proj. Bul. No. 7, p. 4, Fig. 1, OWRR A-045-ARIZ(1). 14-31-001-5003.

Fitzgibbon, J.E., and Dunne, T. 1979. Characteristics of Subarctic Snowcover. Ref.: Hydrological Sci. Bul., Vol. 24, No. 4, pp. 465-476.

Fletcher, J.J., and Rechard, P.A. Water Loss from Snowdrifts under Oasis Conditions. Ref.: Available from the Nat. Tech. Info. Service, Springfield, VA 22161 as PB-263.

Fogel, M.M. Vegetation Management Guidelines for Increasing Water Yields In a Semiarid Region: An Arizona Case Study. Ref.: FAO Conservation Guide 3, Conservation in Arid and Semiarid Zones. pp. 73-84. 1976.

Frank, A.B., and Willis, W.O. 1978. Effect of Winter and Summer Windbreaks on Soil water Gain and Spring Wheat Yield. Soil Sci. Soc. Am. J. 42:950-953.

Gary, H.L. 1974. Snow Accumulation and Melt Along Borders of a Strip Cut in New Mexico. Ref.: U.s. Dept. of Ag. Forest Service Research Note RM-279. p. 8.

- 2 -

Crook, A.G. 1977. Snotel: Monitoring Climatic Factors to Predict Water Supplies. J. of Soil and Water Conservation, Vol. 32, No. 6, pp. 294-295.

Davis, R.J. 1972. United States and Mexico: Weather Technology Water Resources and International Law. Int. Nat. Resources Journal, Vol. 12, No. 4, pp. 530-44.

Davis, R.J. 1978. Weather Modification Law and the Environmental Effects of Snowpack Enhancement (National Environmental Policy Act). Carson City, Proceedings Western Snow Conference, pp. 41-41.

Dobrolenskii, G.A., and Landin, V.P. 1978. Meliorative Effects of Forest Tree Plantings for Erosion Control in Winters with Little Snow (on the Desna River Upland in the Polesye). Kiev, "Urozhai", pp. 45-51.

Essington, E.H., Forslow, E.J., and Tuttle, J.D. 1967. Snow-water Conservation. Part 1; Migration of Evaporation Surpressants Applied To Snow. Publ. Nat. Tech. Info. Serv., p. 89.

Evans, W.E. 1974. Progress in Measuring Snow Cover from ERTS (Earth Resources Technology Satellite) imagery (Remote Sensing). Carson City, Proceedings Western Snow Conference, pp. 37-45.

Farnes, P.E., and Shafer, B.A. Summary of Snow Survey Measurements for Montana, 1922-1974. p. 220.

Ffolliott, P.F., and Thorud, D.B. A Technique to Evaluate Snowpack Profiles in and Adjacent to Forest Openings. In Hydrology and Water Resources in Arizona and the Southwest, Vol. 4., Proceedings of the 1974 Meetings of the AWRA, Arizona Section and The AAS Hydrology Section, Flagstaff, Arizona, pp. 10-17.

Ffolliott, P.F., and Thorud, D.B. 1974. Development of Forest Management Guidelines for Increasing Snowpack Water Yields in Arizona. Arizona Water Resources Project Inform., Proj. Bul. No. 7, p. 4, Fig. 1, OWRR A-045-ARIZ(1). 14-31-001-5003.

Fitzgibbon, J.E., and Dunne, T. 1979. Characteristics of Subarctic Snowcover. Hydrological Sci. Bul., Vol. 24, No. 4, pp. 465-476.

Fletcher, J.J., and Rechard, P.A. Water Loss from Snowdrifts under Oasis Conditions. Available from the Nat. Tech. Info. Service, Springfield, VA 22161 as PB-265.

Fogel, M.M. Vegetation Management Guidelines for Increasing Water Yields in a Semiarid Region: An Arizona Case Study. 1976 FAO Conservation Guide 3, Conservation in Arid and Semiarid Zones. pp. 73-84.

Frank, A.B., and Willis, W.O. 1978. Effect of Winter and Summer Windbreaks on Soil Water Gain and Spring Wheat Yield. Soil Sci. Soc. Am. J., Vol. 42, 950-953.

Gary, H.L. 1974. Snow Accumulation and Melt Along Borders of a Strip Cut in New Mexico. U.S. Dept. of Ag. Forest Service Research Note RM-279, p. 8.

~~Gary, H.L.~~ 1978. Airflow Patterns and Snow Accumulation In a Forest Clearing. ~~Ref.:~~ In: Western Snow Conf. (Coronado, Calif., April 1975) ~~Proc.~~ 43, pp. 106-113. Proceedings Vol. underline

~~Gary, H.L.~~ 1979. Duration of Snow Accumulation Increases after Harvesting in Lodgepole pine in Wyoming and Colorado (Watershed Management, snow hydrology, water yield management). Fort Collins, Colo., The Station. USDA Forest Serv. Research note RM U of S. Rocky Mountain Forest and Range Experiment Station, p. 7.

Golding, D.L., and Swanson, R.H. 1978. Snow Accumulation and Melt in Small Forest openings in Alberta. Ottawa, Nat. Res. Council of Can. pp. 380-388.

Granger, R.J., and Male, D.H. 1978. Melting of a Prairie Snowpack (Runoff). Journ. of applied meteorology, pp. 1833-1842.

Greb, B.W. 1979. Tall Wheatgrass snow barriers on Forage Yields in Northeastern Colorado. Agron. Abstracts, p. 203.

~~Greb, B.W.~~ 1979. Tall Wheatgrass Barriers show Control. Crops & Soils. pages?

~~Greb, B.W.~~ 1979. Water Conservation Practices - Central Great Plains. ASA Monograph "Dryland Agriculture in North America", part of Ch. 2. pages?

~~Greb, B.W.~~ 1979. Influence of Tall Wheatgrass snow Barriers on Forage Yields in Semiarid Northeastern Colorado. Soil Sci. Soc. Am. J. pages? + volume no?

~~Greb, B.W.~~ 1980. Snowfall and its Potential Management in the West-Central Great Plains. USDA-ARR-W-1 Series Bulletin, Western Region SEA-AR. l.c. pages

Halverson, H.G. 1972. Seasonal Snow Surface Energy Balance In a Forest Opening. ~~Ref.:~~ Atomic Energy Commission, Oak Ridge, Tenn., Tech. Info. Centre, TID 26242, p. 73.

~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 36 Degrees North. ~~Ref.:~~ Forest Service - PSW-102, p. 49.

~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 40 Degrees North. ~~Ref.:~~ Forest Service-PSW-102, p. 49.

~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 38 Degrees North. ~~Ref.:~~ Forest Service-PSW-102, p. 49.

~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 48 Degrees North. ~~Ref.:~~ Forest Service-PSW-102, p. 49.

~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 46 Degrees North. ~~Ref.:~~ Forest Service-PSW-102, p. 49.

~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 44 Degrees North. ~~Ref.:~~ Forest Service-PSW-102, p. 49.

2 Halverson, H.G., and Smith, J.L. 1974. Shadow Length Tables for Environmental Planning. ~~Ref.:~~ Report PSW-102. pages

3 ~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 50 Degrees North. ~~Ref.:~~ Forest Service-PSW-102, p. 49. m

8 ~~Halverson, H.G., and Smith, J.L.~~ 1974. Shadow Length Tables for Latitude 42 Degrees North. ~~Ref.:~~ Forest Service-PSW-102, p. 49. m

Haupt, H.P. 1973. Relation of Wind Exposure and Forest Cutting to Changes in Snow Accumulation. Publ. UNESCO, J Proc Banff Symp. ~~-~~ Sept. 1972 ~~-~~ Role of Snow and Ice in Hydrology, Vol. 002, pp. 1399-1409. sp.

Hibbert, A.R. 1977. Potential for Augmenting Flow of the Colorado River by Vegetation Management. ~~Ref.:~~ In: Proceedings, 21st Annual Arizona Watershed Symp., Tuscon, Arizona, Arizona Water Commission Report No. 10, pp. 16-21. underline sp.

~~Hibbert, A.R.~~ 1979. Vegetation Management for Water Yield Improvement in the Colorado River Basin. ~~Ref.:~~ Available from the Nat. Tech. Info. Service, Springfield, VA. p. 58. m

Hoover, M.D. 1971. Snow Interception and Redistribution in the Forest. ~~Ref.:~~ In: Biological Effects In the Hydrological Cycle, Proceedings ~~of the~~ Third International Seminar for Hydrology Professors, Purdue University, West Lafayette, Indiana, pp. 114-122. underline

Howell, W.E. 1973. Impact of Snowpack Management on Snow and Ice Hydrology. Publ. UNESCO, J. Proc. Banff Symp. ~~-~~ Sept. 1972 ~~-~~ Role of snow and ice in hydrology, Vol. 002, pp. 1464-1472. sp.

Jones, M.E. 1974. Differential Release of Water from Arizona Snowpacks. ~~Ref.: Arizona University,~~ Tucson, Department of Watershed Management, MS Thesis, p. 53. l.c. Univ. of Arizona tr.

Kirdar, E. Arizona's Frozen Assets: Volumetric Forecasts from Snowpack. ~~Ref.:~~ 19th Annual Arizona Watershed Symp. Proceedings, Report No. 7, pp. 37-38. tr. sp.

Krouse, H.R., and Smith, J.L. 1972. 018/016 Abundance Variations in Sierra Nevada Seasonal Snowpacks and Their use in Hydrological Research. ~~Ref.:~~ In: Proceedings Inter. Hydrolic Decade Snow and Ice, Banff, Canada. pp. 24-38. underline sp.

Kuligin, S.M., and Teriukov, A.G. 1978. Water Regime of Soils in the Green Canopies of the Volga Area (Effects of snow cover and temperature on soil freezing and thawing). Ashkhabad, "Ylym", pp. 61-64. tr.

Lachapelle, E.R. Alternate Methods for the Artificial Release of Snow Avalanches. I Symp. on Applied Glaciology: Proceedings ~~of the~~ Fourth Symp. ~~on~~ Glaciology, Cambridge (England) Sept. 13-17, 1976. J. of Glaciology, Vol. 19, No. 81, pp. 389-397. sp. sp. sp.

Lang, T.E., and Sommerfeld, R.A. 1977. The Modeling and Measurement of a Sloping Snow Pack. ~~Ref.:~~ In: Symp. on Applied Glaciology, Proceedings of the Fourth Symp. of Glaciology, Cambridge (England) Journal of Glaciology, Vol. 19, No. 81, pp 153-163. underline

Linlor, W.I. Remote Sensing and Snowpack Management. 1974. J of the Amer. Water Works Assoc., Vol. 66, No. 9, pp 553-558, ~~Sept. 1974.~~ September

Linlor, W.I., Clapp, F.D., and Meier, M.F. 1975. Snow Wetness Measurements for Melt Forecasting. ~~Ref.:~~ In: Proceedings Workshop on Operational Applications of Satellite Snowcover Observations, South Lake Tahoe, Calif., Nat. Aeronautics and Space Admin. pp 375-397. underline l.c.

Linlor, W.I., Smith, J.L., Meier, M.F., Clapp, F.C., and Angelakos, D. 1975. Measurement of Snowpack Wetness. ~~Ref.:~~ In: Proceedings 43rd Annual Meeting Western Snow Conference, Coronado, Calif., Measurement of Snowpack Wetness, pp 14-20.

Lorencik, L., and Mati, R. 1979. Dynamics of soil Moisture with Winter Wheat Grown in the East Slovakian Lowland. Praha, Ustav. pp 323-332.

McAndrew, D.W. Snow Load Analysis and Recreational uses of Snow Data. ~~Ref.:~~ An Interdisciplinary Symp., held at Monteroy, Calif., Dec. 2-6, 1973: Nat. Acad. of Sci., Washington, D.C. pp 11-21. Monterey

McAda, D.P., and Ffolliott, P.F. 1978. Solar Radiation as Indexed by Clouds for Snowmelt Modeling. ~~Ref.:~~ In: Hydro. and Water Res. in Arizona and The Southwest Proceedings of the 1978 meetings of the Arizona Section-American Water Resources Assoc. and the Hyrdo. Section-Arizona Acad. of Sci. Vol. 8, pp 175-181. underline sp. sp.

McMillan, M.C., and Smith, J.L. 1975. Remote Sensing of Snowpack Density using shortwave Radiation. ~~Ref.:~~ In: Proceedings workshop on operational applications of satellite snowcover observations, South Lake Tahoe, Calif., National Aeronautics and Space Admin. pp 361-374. underline

Makarychev, N.T. 1978. Aerodynamic properties of Forest Plantings which Retain Snow. Moskva "Transport" Russian SFSR, p 121. l.c.

Martinelli, M. Jr. 1975. Water-yield Improvement from Alpine Areas: The Status of our knowledge. ~~Ref.:~~ Research paper RM-138, p 16.

Nydahl, J., and Pell, K. 1974. Low Reynolds Number Sublimation of Blown Snow. ~~Ref.:~~ Available from the Nat. Tech. Info. Serv. Springfield, VA. 22161, ~~as~~ PB-237 513. Completion Report (1974) p 35.

Obrebski, T. 1979. The Agrometeorological Characteristics of Snow Cover in Poland from the Standpoint of the Protection of Winter Crops against Frost. pp 1-3. l.c.

O'Brien, P.J., Levins, P.L., and Summers, C.H. 1974. Chemical Impact of Snow Dumping Practices. ~~Ref.:~~ Available from the Nat. Tech. Info. Service, Springfield, VA 22161, p 39.

Pepe, J.F., and Welsh, J.R. Soil Water depletion Patterns under Dryland Field Conditions of closely related Height Lines of Winter Wheat (Dwarfing Genes). Madison, Wis., Crop Sci. Soc. of Amer. pp 677-680. sp.

Potushanskii, V.A. 1978. Strips (from tall field crops for snow accumulation) on the Fields in the Middle Volga area. Moskva, Izdatel'stvo "Kolos" pp 41-42.

Rauzi, F., and Landers, L. Level bench Terraces for Increasing Forage Production in the Northern Great Plains. J. Range Mgmt. volume + pages?

Rawls, W.J., and Jackson, T.J. 1979. Pattern Recognition Analysis of Snowdrifts. Ref.: Nordic Hydrology, Vol. 10, No. 4, pp 251-260.

Rechard, P.A. 1972. Winter Precipitation Gage Catch in Windy Mountainous Areas. ~~Ref.: In:~~ Distribution of Precipitation in Mountainous Areas, Vol. II; Proceedings of the Geilo Symp. Geilo, Norwasy, Jy, World Metrological Organization Publication No. 326 (Vol. 2), Geneva Switzerland, pp 13-26. underline sp.

Rechard, P.A., and Raffelson, C.N. 1974. Evaporation from Snowdrifts under Oasis Conditions. ~~Publ.~~ National Academy of Sci. J. Publ. Advanced Concepts and Techniques in The Study of Snow and Ice Resources. pp 99-107.

Regelin, W.L., and Wallmo, O.C. 1975. Carbon Black Increases Snowmelt and Forage Availability on Deer Winter Range in Colorado. ~~Ref.:~~ U.S. Dept. of Ag. Forest Service, Research Note RM-296, p 4. sp.

Schultz, R.W. 1973. Snowmelt Lysimeters Perform Well In Cold Temperatures In Central Colorado. ~~Ref.:~~ Research Note RM-247, p 8.

Slaughter, C.W., and Crook, A.G. 1974. The Arctic and Subarctic Seasonal Snowpack: Research and Management Approaches in Alaska. ~~Ref.: In:~~ Advanced Concepts and Techniques in the study of Snow and Ice. Nat. Acad. of Sci. Washington, D.C., pp 273-282. ~~1974.~~ underline

Slaughter, C.W., Mellor, M., Sellmann, P.V., and Brown, J. Accumulating Snow to Augment the Fresh Water Supply at Barrow, Alaska. ~~Ref.:~~ Available from the Nat. Tech. Info. Service, Springfield, VA 22161 ~~as~~ (ADA-005-031), Jan. 1975, p 21. sp.

Slukhai, S.I., and Kirichenko, V.P. 1978. Water Consumption of Winter Wheat at Different Soil Moisture and Other Conditions of Growing. Kiev, "Naukova Dumka" pp 250-256.

~~Smith, J.L., Halverson, H.G., and Jones, R.A.~~ 1972. Development of a Radioactive Isotope Profiling Snow Gage. ~~Ref.:~~ Atomic Energy Commission, Oak Ridge, Tenn., Tech. Info. Centre, p 86. tr.

Smith, J.L., Halverson, H.G., and Jones, R.A. 1972. Central Sierra Profiling Snow Gage: A guide to Fabrication and Operation. ~~Ref.:~~ Atomic Energy Commission, Oak Ridge, Tenn., Tech. Info. Centre, p 53.

Snyder, J.R., Skold, M.D., ~~and~~ Willis, W.O. 1979. The Economics of Snow Management: an Application of Game Theory. West. J. Agr. Econ. volume + pages?

Pepe, J.F., and Welsh, J.R. Soil Water depletion Patterns under Dryland Field Conditions of closely related Height Lines of Winter Wheat (Dwarfing Genes). Madison, Wis., Crop Sci. Soc. of Amer., pp 677-680.

Potushanskii, V.A. 1978. Strips (from tall field crops for snow accumulation) on the Fields in the Middle Volga area. Moskva, Izdatel'stvo "Kolos" pp 41-42.

Rauzi, F., and Landers, L. Level bench Terraces for Increasing Forage Production in the Northern Great Plains. J. Range Mgmt.

Rawls, W.J., and Jackson, T.J. 1979. Pattern Recognition Analysis of Snowdrifts. Ref.: Nordic Hydrology, Vol. 10, No. 4, pp 251-260.

Rechard, P.A. 1972. Winter Precipitation Gage Catch in Windy Mountainous Areas. Ref.: In: Distribution of Precipitation in Mountainous Areas, Vol. II; Proceedings of the Geilo Symp. Geilo, Norway, Jy, World Metrological Organization Publication No. 326 (Vol. 2). Geneva Switzerland, pp 13-26.

Rechard, P.A., and Raffelson, C.N. 1974. Evaporation from Snowdrifts under Oasis Conditions. Publ. National Academy of Sci. In Advanced Concepts and Techniques in The Study of Snow and Ice Resources, pp 99-107.

Regelin, W.L., and Wallmo, O.C. 1975. Carbon Black Increases Snowmelt and Forage Availability on Deer Winter Range in Colorado. Ref.: U.S. Dept. of Ag. Forest Service, Research Note RM-296, p.4.

Schultz, R.W. 1975. Snowmelt Lysimeters Perform Well in Cold Temperatures in Central Colorado. Ref.: Research Note RM-247, p 8.

Slaughter, C.W., and Crook, A.G. (1974) The Arctic and Subarctic Seasonal Snowpack: Research and Management Approaches in Alaska. Ref. In: Advanced Concepts and Techniques in the study of Snow and Ice. Nat. Acad. of Sci. Washington, D.C., pp 273-282. ~~1974~~

Slaughter, C.W., Mellor, M., Sellmann, P.V., and Brown, J. Accumulating Snow to Augment the Fresh Water Supply at Barrow, Alaska. Ref.: Available from the Nat. Tech. Info. Service, Springfield, VA 22161 as ADA-005-031, Jan. 1975, p 21.

Slukhai, S.I., and Kirichenko, V.P. 1978. Water Consumption of Winter Wheat at Different Soil Moisture and Other Conditions of Growing. Kiev, "Naukova Dumka" pp 250-256.

Smith, J.L., Halverson, H.G., and Jones, R.A. 1972. Development of a Radioactive Isotope Profiling Snow Gage. Ref.: Atomic Energy Commission, Oak Ridge, Tenn., Tech. Info. Centre, p 86.

Smith, J.L., Halverson, H.G., and Jones, R.A. 1972. Central Sierra Profiling Snow Gage: A guide to Fabrication and Operation. Ref.: Atomic Energy Commission, Oak Ridge, Tenn., Tech. Info. Centre, p 53.

Snyder, J.H., Skold, M.D., and Willis, W.O. 1979. The Economics of Snow Management: an Application of Game Theory. West. J. Agr. Econ.

Sommerfeld, R.A. 1974. A Weibull Prediction of the Tensile Strength-Volume Relationship of Snow. ~~Ref.:~~ J. of Geophysical Research, Vol. 79, No. 23, pp. 3353-3356.

Starygin, M.A. 1978. Winter wheat on the fields of the Transvolga Area (Methods of Soil moisture conservation on variety testing farms). Moskva, Izdatel'stvo "Kolos" pp. 28-29.

Storr, D. 1973. Wind-Snow Relations at Marmot Creek, Alta. ~~Ref.:~~ Can. J. for Res., Vol. 3, No. 4, pp. 479-485.

Sturges, D.L. 1975. Oversnow Runoff Events Affect Streamflow and Water Quality. ~~Ref.:~~ In: Proceedings, Snow Management on the Great Plains Symp., Bismarck, N.D., pp. 105-117.

Super, A.B., Heimbach, J.A., McPartland, J.T., and Mitchell, V.L. 1974. Atmospheric Water Resources Management Program-Bridger Range Cloud Seeding Experiment. Ref.: Available from the National Tech. Info. Service, Springfield, VA 22161, AS PB-234 012, p. 416.

Suskevic, M., and Odlozilik, S. 1979. Soil Moisture Content and the Grain Yield of Winter Wheat Grown after Winter Wheat in minimally cultivated or Uncultivated Soil (Plowing, forecrop). Praha, Ustav, pp. 945-952.

Swanson, R.H. 1973. Small openings in poplar forest Increase Snow Accumulation. Publ. UNESCO J. Proc. Banff Symp. - Sept. 1972 - Role of Snow and Ice in Hydrology. Vol. 002, pp. 1382-1390.

Tabler, R.D. 1973. New Snow Fence Design Controls Drifts, improves Visibility, Reduces road Ice. ~~Ref.:~~ In: Annual Transportation Engineering Conf. (Col. Univ., Denver) pp. 16-27.

Teller, H.L., Klein, D.A., and Cameron, D.E. 1973. General Disposition and Aquatic Environmental Effects of Silver Iodid. ~~Ref.:~~ In: Water for Human Environment, Vol. IV, special Sessions: Proceedings of the First World Congress on Water Resources (Vol. 4), Chicago, Ill., pp. 537-547.

Tennyson, L.C., Ffolliott, P.F., and Thorud, D.B. 1974. Use of Time-Lapse Photography To Assess Potential Interception In Arizona Pondersoa Pine. Ref.: Water Resources Bulletin, Vol. 10, No. 6, pp. 1246-1254.

Thorud, D.B., and Ffolliott, P.F. 1975. Arizona's Frozen Assets: Snowpack Management. ~~Ref.:~~ In: 19th Annual Arizona Watershed Symp. Proceedings, Report No. 7, pp. 31-34.

Unger, P.W., and Wiese, A.F. 1979. Managing irrigated Winter Wheat Residues for Water Storage and Subsequent Dryland Grain Sorghum Production (Effects of Tillage, Residue levels, and soil water content). Madison, Wis., Soil Sci. Soc. of Amer. pp. 582-588.

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Sommerfeld, R.A. 1974. A Weibull Prediction of the Tensile Strength-Volume Relationship of Snow. Ref.: J. of Geophysical Research, Vol. 79, No. 23, pp 3353-3356.

Starygin, M.A. 1978. Winter wheat on the fields of the Transvolga Area (Methods of soil moisture conservation on variety testing farms). Moskva, Izdatel'stvo "Kolos" pp 28-29.

Storr, D. 1973. Wind-Snow Relations at Marmot Creek, Alta. Ref.: Can. J. for Res., Vol. 3, No. 4, pp 479-485.

Sturges, D.L. 1975. Oversnow Runoff Events Affect Streamflow and Water Quality. Ref.: In: Proceedings, Snow Management on the Great Plains Symp., Bismarck, N.D., pp 105-117.

Super, A.B., Heimbach, J.A., McPartland, J.T., and Mitchell, V.L. 1974. Atmospheric Water Resources Management Program-Bridger Range Cloud Seeding Experiment. Ref.: Available from the National Tech. Info. Service, Springfield, VA 22161, as PB-234 012, p 416.

Suskevic, M., and Odlozilik, S. 1979. Soil Moisture Content and the Grain Yield of Winter Wheat Grown after Winter Wheat in minimally cultivated or Uncultivated Soil (Plowing, forecrop). Praha, Ustav, pp 945-952.

Swanson, R.H. 1975. Small openings in poplar forest increase Snow Accumulation. Publ. UNESCO] J. Proc. Banff Symp., Sept. 1972. Role of Snow and Ice in Hydrology. Vol. 002 pp 1382-1390.

Tabler, R.D. 1973. New Snow Fence Design Controls Drifts, Improves Visibility, Reduces road Ice. Ref.: In: Annual Transportation Engineering Conf. (Colo Univ., Denver) pp 16-27.

Teller, H.L., Klein, D.A., and Cameron, D.E. 1973. General Disposition and Aquatic Environmental Effects of Silver Iodide. Ref.: In: Water for Human Environment, Vol. IV, special Sessions: Proceedings of the First World Congress on Water Resources (Vol. 4), Chicago, Ill., pp 537-547.

Tennyson, L.C., Ffolliott, P.F., and Thorud, D.B. 1974. Use of Time-Lapse Photography To Assess Potential Interception in Arizona Ponderosa Pine. Ref.: Water Resources Bulletin, Vol. 10, No. 6, pp 1246-1254.

Thorud, D.B., and Ffolliott, P.F. 1975. Arizona's Frozen Assets: Snowpack Management. Ref. In: 19th Annual Arizona Watershed Symp., Proceedings, Report No. 7, pp 31-34.

Unger, P.W., and Wiese, A.F. 1979. Managing Irrigated Winter Wheat Residues for Water Storage and Subsequent Dryland Grain Sorghum Production (Effects of Tillage, Residue levels, and soil water content). Madison, Wis., Soil Sci. Soc. of Amer. pp 582-588.

Volokhov, I.I. 1978. Fallow Soil, the Best Precursor (for winter wheat in Rostov Region) (Methods of Soil Moisture Conservation on Variety Testing Farms). Moskva, Izdatel'stvo "Kolos" pp 27-28.

Wakahama, G., Kuroiwa, D., and Gota, K. 1977. Snow Accretion on Electric Wires and its Prevention. J. of Glaciology, Vol. 19, No. 81, pp 479-487.

l.c. Warren, M.A. 1974. Snowpack Dynamics in Relation To Inventory-Prediction Variables In Arizona Mixed-Conifer. ~~Ref.:~~ [~~Master of Science~~ Thesis]. p 77. where?

Warren, M.A., and Ffolliott, P.F. 1975. Describing Snowpacks in Arizona mixed confier Forrests with a Storage Duration Index. Ref.: ~~In:~~ Vol. 5, Hydrology and Water Resources in Arizona and the Southwest, Proceedings of ~~the~~ 1975 meetings of the Arizona Section, Amer. Water Res. Assoc. and the Hydro. Section, Arizona Academy of Sci. pp 87-89. tr, earch

Warskow, W.L. 1975. Aerial Snowpack Mapping. ~~Ref.:~~ In: Vol. 5: Hydrology and Water Resources in Arizona and the Southwest, Proceedings ~~of the~~ 1975 mettings of the Arizona Section, ~~American~~ Water Resources Assoc. and the Hydro. Section. Arizona Acad. of Sci. pp 207-213. underline

Weisbecker, L.W., 1974. Snowpack, Cloud-seeding, and the Colorado River. (1st ed.) ~~Norman, U of Okl. Press,~~ p 86. tr,
Univ. of Oklahoma Press, Norman, Oklahoma,

Welch, B.W. 1975. Validation of Snowpack Inventory Prediction Relationships in Arizona Ponderosa Pine Forests. ~~Ref.:~~ [~~Master of~~ Science Thesis], p 59. where?

Wight, J.R., and Black A.L. 1978. Soil Water Use and Recharge in a Fertilized Mixed Prairie Plant Community. J. Range Mgmt. ~~(31(4):280-282).~~
Vol. 31, No.4, pp. 280-282,

Willis, W.O., Bauer, A., and Black, A.L. Water Conservation: The Northern Great Plains. ASA Dryland Agriculture Monograph. volume + pages?

Aase, J. K. and F. H. Siddoway. 1974. Tall wheat grass barriers and winter wheat response. Agric. Meteorology 13: 321-328.

Aase, J. K. and F. H. Siddoway. 1976. Influence of tall wheat grass wind barriers on soil drying. Agron. 68: 627-631.

Aase, J. K., F. H. Siddoway, and A. L. Black. 1976. Perennial grass barriers for wind erosion control, snow management and crop production. In Shelterbelts on the Great Plains, Great Plains Agr. Council Publ. 78, pp. 69-76. underline

Agriculture Research Service. 1977. North Dakota Progress Report on Research on Reclamation of Strip Mined Lands - Update 1977. Agriculture Research Service, U.S.D.A. and North Dakota Agricultural Experiment Station, March 1977. pages?

ARS Prog. Report here

Aldon, E. F. 1978. Reclamation of coal mined land in the Southwest. J. ~~of~~ Soil and Water Conservation, March-April 1978 33(2). pages?

Anderson, C. H. 1971. Comparison of tillage and chemical summer-fallow in a semi-arid region. Can. J. ~~of~~ Soil Sci. 51(3): 397-403.

Anderson, C. H. and F. Bisal. 1969. Snow cover effect on the erodible soil fraction. Can. J. Soil Sci. 49: 287-296.

Anderson, C. H. and D. W. L. Read. 1966. Water use efficiency of some varieties of wheat, oats, barley, and flax grown in the greenhouse. Can. J. Plant Sci. 46: 375-378.

Anderson, D. T. 1961. Surface trash conservation with tillage machine. Can. J. Soil Sci. 41: 99-114.

~~Anderson, D. T.~~ 1967. The cultivation of wheat. In Proc. of Canadian Centennial Wheat Symposium K. F. Neilson (Editor) Westerly Coop. Fertilizer Ltd. Modern Press, Saskatoon, Sask., pp. 338-355. underline sp l.c. sp.

Aase, J. K. and F. H. Siddoway. 1974. Tall wheat grass barriers and winter wheat response. Agric. Meteorology 13: 321-328.

Aase, J. K. and F. H. Siddoway. 1975. Influence of tall wheat grass wind barriers on soil drying. Agron. 68: 627-631.

Aase, J. K., F. H. Siddoway, and A. L. Black. 1976. Perennial grass barriers for wind erosion control, snow management and crop production. In Shelterbelts on the Great Plains, Great Plains Agr. Council Publ. 78, pp. 69-75.

Agriculture Research Service. 1977. North Dakota Progress Report on Research on Reclamation of Strip Mined Lands - Update 1977. Agriculture Research Service, U.S.D.A. and North Dakota Agricultural Experiment Station, March 1977.

Aldon, E. F. 1978. Reclamation of coal mined land in the Southwest. J. of Soil and Water Conservation, March-April 1978 33(2).

Anderson, C. H. 1971. Comparison of tillage and chemical summer-fallow in a semi-arid region. Can. J. of Soil Sci. 51(3): 397-403.

Anderson, C. H. and F. Bisal. 1969. Snow cover effect on the erodible soil fraction. Can. J. Soil Sci. 49: 287-296.

Anderson, C. H. and D. W. L. Read. 1966. Water use efficiency of some varieties of wheat, oats, barley, and flax grown in the greenhouse. Can. J. Plant Sci. 46: 375-376.

Anderson, D. T. 1961. Surface trash conservation with tillage machine. Can. J. Soil Sci. 41: 99-114.

Anderson, D. T. 1967. The cultivation of wheat. In Proc. of Canadian Centennial Wheat Symposium K. F. Neilson (Editor) Westerly Coop. Fertilizer Ltd. Modern Press, Saskatoon, Sask., pp. 238-255.

Anderson, D. T. and R. G. Russel. 1964. The effects of various quantities of straw on the growth and yield of spring and winter wheat. Can. J. Soil Sci. 44(1): 109-119.

Arnold, K. C. 1961. An investigation into methods of accelerating the melting of ice and snow by artificial dusting. Geology of the Arctic, pp. 989-1013.

Atkinson, H. B., and C. E. Bay. 1940. Some factors affecting frost penetration. E.O.S. Trans. Amer. Geophys. Union, pp. 935-948.

Ayers, H. D. 1959. Influence of soil profile and vegetation characteristics on net supply to runoff. Proc. Symp. No. 1 Spillway Design Floods, Queen's Printer Ottawa, Canada, pp. 198-205.

Bakeav, N. 1970. Banded cover crops for fallow in Northern Kazakstan. Zemledeliya No. 10: 19-21. Translated by Can. Dept. Agri. Ottawa, 3 p.

Barnes, O. K. 1952. Pitting and other treatments on native range. Wyo. Agri. Sta. Bull. 318, 23 p.

Barnes, O. K., D. Anderson and A. Heerwagen. 1958. Pitting for range improvement in the Great Plains and the Southwest Desert Regions. U.S.D.A. Prod. Res. Rept. 23, 17 p.

Barnes, O. K., and A. L. Nelson. 1945. Mechanical treatment for increasing the grazing capacity. Wyo. Exp. Sta. Bull. 273, 23 p.

Barnes, S. 1938. Soil moisture and crop production under dryland conditions in western Canada. Can. Dept. Agric. Publ. 595, 43 p.

Bauder, J. W., L. J. Brun, and T. H. Krueger. 1975. The relationship of soil freezing to snowmelt runoff. North Dakota Farm Res. 32(6): 10-13.

Bauer, A., W. A. Berg, and W. L. Gould. 1978. Correction of nutrient deficiencies and toxicities in strip mined lands in arid and semiarid regions. Reclamation of Drastically Disturbed Lands, pp. 451-456.

Bauer, A., and H. L. Kucera. 1978. Effect of tillage on some soil physiochemical properties on an annually cropped spring wheat yields. Agri. Exp. Sta. N. Dakota State Univ. Bull. 506: 102 p.

Bauer, A., and R. A. Young. 1966. Fertilized wheat uses water more efficiently. North Dakota Farm Research 24(3): 4-11.

Bay, C. E., G. W. Wunnecke, and O. E. Hays. 1952. Frost penetration into soils as influenced by depth of snow, vegetative cover, and air temperatures. E.O.S., Transactions of Amer. Geophys. Union 33: 541-546.

Beard, J. B. 1973. Turfgrass: Science and Culture. Prentice-Hall. Inc., Englewood Cliffs, N.J., 658 p.

Beaumont, R. T. 1966. Snow accumulation, Proc. 34th Meeting Western Snow Conf. pp. 3-6.

Bellman, E., and F. H. Theakston. 1965. Artificial snow and wind barriers around open-front livestock buildings. Canadian J. Agric. Engineering 7(1): 1-4.

Benz, L. C., F. M. Sandoval, and W. O. Willis. 1967. Soil salinity changes with fallow and a straw mulch on fallow. Soil Sci. 104(1): 63-68.

Benz, L. C., W. O. Willis, F. M. Sandoval, and R. H. Mickelson. 1968. Soil water translocation in a high water table area. Water Resources Res. 4: 95-101.

Berndt, H. W. 1964. Inducing snow accumulation on mountain grassland watersheds. J. Soil and Water Conservation 19: 196-198.

Black, A. L. 1970. Soil water and soil temp. influences on dryland winter wheat. Agron. J. 62: 797-801.

~~Black, A. L.~~ 1973. Soil property changes associated with crop residue management in a wheat fallow rotation. Soil Sci. Soc. Am. Proc. 37(6): 943-946.

Black, A. L., and B. W. Greb. 1971. Vegetative barriers and artificial fences for managing snow in Central and Northern Plains. Proc. of the Snow and Ice in Relation to Wildlife and Recreation Symposium, pp. 96-111.

Black, A. L., and L. L. Reitz. 1970. Grasses grown in contour rows. Northern Plains Branch. Soil and Water Conservation Research Division 1970.

~~Black, A. L., and L. L. Reitz~~. 1979. Excellent potential: Grasses grown in contour rows. Montana Farmer-Stockman 57(16): 36, 38 and 40.

Black, A. L., and F. H. Siddoway. 1971. Tall wheatgrass barriers for soil erosion control and water conservation. J. Soil and Water Conservation 26(3): 107-111.

~~Black, A. L., and F. H. Siddoway~~. 1975. Snow trapping and crop management with tall wheat grass barriers in Montana. In Snow Management on the Great Plains, Great Plains Agr. Council University of Nebraska Exp. Sta. (Lincoln, Neb.) Publ. 73, pp. 128-137.

~~Black, A. L., and F.H. Siddoway~~. 1976. Dryland cropping sequences within a tall wheat grass barrier system. J. Soil and Water Conservation 31: 101-105.

Black, A. L., F. H. Siddoway, and R. W. Saulmon. 1971. Wheat grass barriers stop soil blowing, trap water. Montana Farmer-Stockman 58(16): 6, 8 and 10.

Blaney, H. F. 1959. Monthly consumptive use requirements for irrigated crops, J. Irrigation and Drainage Div., Amer. Soc. Civil Engin. 85(IR1)Part 1: 1-2.

Bole, J. B., and U. J. Pittman. 1978. The effect of fertilizer N, spring moisture, and rainfall on yield and protein content of barley in Alberta. Proc. 1978 Soils and Crops Workshop, Soil Mgt. 510 Publ. 390, 114-121. (Extension Service, Univ. of Saskatchewan, Saskatoon, Sask.).

Bond, J. J., J. F. Power, and W. O. Willis. 1971. Soil water extraction by N-fertilized spring wheat. Agron. J. 63: 280-283.

~~Bond, J. J., J. K. Power, and W. O. Willis~~. 1971. Tillage and crop residue management during seedbed preparation for continuous spring wheat. Agron. J. 63: 789-793.

Bowren, K. E., and R. D. Dryden. 1971. Effect of fall and spring treatment of stubble land on yield of wheat in the Black Soil Region of Manitoba and Saskatchewan. Canadian Agric. Engineer 13(1): 32-35.

Branson, F. A., R. F. Miller, and I. S. McQueen. 1962. Effects of contour furrowing, grazing intensities, and soils on infiltration rates, soil moisture and vegetation near Fort Peck, Montana, J. of Range Management 15: 151-158.

~~Branson, F. A., R. F. Miller, and I. S. McQueen~~. 1966. Controu furrowing, pitting, and ripping on rangelands of the western U.S. J. of Range Management 19: 182-190.

Brown, P. L., and M. R. Miller. 1978. Soil and crop management practices to control saline seeps in the U.S. northern plains. Proc. Dryland Saline Seep Control Meeting, 11th Int. Soil Sci. Congress, Edmonton, Alberta, pp. 1-7.

Budd, W. F. 1966. Glaciological studies in the region of Wilkes, Eastern Antarctica, 1961. Publ. 88, Issued by Antarctic Division. Dept. of External Affairs, Melbourne, pp. 51-85.

Burwell, R. E., L. L. Sloneker, and W. W. Nelson. 1968. Tillage influences water intake. J. Soil and Water Conserv. 23: 185-187.

Carder, A. C., and A. M. F. Hennig. 1966. Soil moisture regimes under summerfallow, wheat and red fescue in the upper Peace River Region. Agri. Meteorol. 3: 311-331.

Chacho, E., and M. Molnau. 1980. Snow drifting on phosphate mine dumps in Southeastern Idaho. Proc. 48th Meeting Western Snow Conf., Laramie, Wyo. April 1980.

Cole, John S. 1938. Correlations between annual precipitation and yield of spring wheat in the Great Plains. U.S.D.A. Technical Bull. No. 636.

Coligado, M., W. Baier, and W. Sly. 1968. Risk analysis of weekly climatic data for agricultural and irrigation planning. Agrometeorology Section, Agriculture Canada, Tech. Bull 34(Brandon), 38(Melfort), 40(Regina), 43(Swift Current), 44 (Beaverlodge).

Connaughton, C. A. 1935. The accumulation and rate of melting of snow as influenced by vegetation. J. For 33: 564-569

Copeland, O. L., and P. E. Packer. 1972. Land use aspects of the energy crisis and western mining. J. of Forestry 70(11): 671-675.

Coxworth, E., D. Thompson, and M. Gimby. 1978. Energy, agriculture and the food system. Unpublished Sask. Res. Council Report C78-9 for D.S.S. contract File No. 07SZ.01843-7-0750: 81 p.

Crabb, G. A., and J. L. Smith. 1952. Soil-temperature comparisons under varying covers. Highway Res. Abstr. 22:67-68.

Crawford, C. B., and R. F. Legget. 1957. Ground temperature investigations in Canada. Eng. J. 40:1-8.

Curtis, W. R. 1971. Terraces reduce runoff and erosion on surface mine benches. J. Soil and Water Conservation, 26: 198-199.

Dawley, W. K., R. D. Dryden, E. V. McCurdy, E. S. Molberg, K. E. Bowren, and D. A. Dew. 1963. The effect of cultural and fertilizer treatments on yields of wheat on second cropland. Can. J. of Soil Science 44(1964).

Deibert, E. J. 1979. No-till influence on soil temperature, moisture and compaction. Proc. Manitoba-North Dakota Zero Tillage Workshop, Brandon, Manitoba, pp. 1-13.

de Jong, E., and D. A. Rennie. 1969. Effect of soil profile type and fertilizer on moisture use by wheat grown on fallow or stubble land. Can. J. Soil Sci. 49: 189-197.

de Jong, E., and H. Steppuhn. At press. Water conservation on the Canadian Prairies. In Chap. 2. Water Relations. Monograph on Dryland Agriculture, Am. Agronomy and Soil Sci. Soc.

Den, U. D. 1936. The zone of effective windbreak influence. J. Forestry 34: 689-695.

de Vore, N. III. 1976. Growing up in Montana - a picture essay. J. Nat. Geographic Soc. 149(5): 650-657. (May 1976 issue).

de Vries, D. A. 1975. Heat transfer in soils. Chpater 1, pp. 5-28. In Heat and Mass Transfer in the Biosphere, Part 1, Transfer processes in the plant environment, D. A. de Vries and N. H. Afgan (Editors), Scripta Book Co., Washington: 594 p.

Dingman, S. L. 1975. Hydrologic effects of frozen ground literature review and synthesis. U. S. Army Corps of Engineers, CRREL, Cold Regional Res. & Engineering Lab., Special report 218: 55p.

Division of Hydrology. 1968-1975. Precipitation Data. Bad Lake Climatological Station at Bickleigh, Sask. Univ. of Sask. Saskatoon (unpublished data).

Dkysterhuis, E. J. 1949. Condition and management of rangeland based on quantitative ecology. J. Range Management 2: 104-115.

Doering, E. J., and C. R. Reeve. 1965. Engineering aspects of the reclamation of sodic soils with high salt waters. J. of the Irrigation and Drainage Division, Proc. of the American Society of Civil Engineers (Paper No. 4588) 91(IR4): 59-72.

Doering, E. J., and F. M. Sandoval. 1975. Hydrologic aspects of saline seeps in southwestern North Dakota. Reprinted from Proc. of Regional Saline Seep Sympsoium Dec. 1975.

Doering, E. J., and W. O. Willis. 1975. Chemical reclamation for sodic strip-mine spoils, Agricultural Research Service, U.S.D.A. ARS-NC-20, pp. 1-8.

Doty, Robert D. 1970. Inlfuence of contour trenching on snow accumulation. J. of Soil and Water Conservation (May-June) 25: 102-104.

Dubetz, S. 1961. Effect of soil type, soil moisture, and nitrogen fertilizer on the growth of spring wheat. Can. J. Soil Sci. 41(1): 44-51.

Dyck, G. E., D. E. L. Erickson, and H. Steppuhn. 1978. Snow ridging to increase soil water. Proc. Soils and Crops Workshop. Univ. of Sask. Extension Div. Pub. 403 Soil Management 510, Saskatoon, Sask., pp. 1-12.

~~Dyunin, A. K.~~ m 1959. Fundamentals of the theory of snow drifting. Izvest. Sibirsk Otdel. Akad. Nauk. U.S.S.R. 12: 11-24. 1961 Tech. Translation 952, Nat. Res. Council Canada, 26 p.

tr, Dyunin, A. K. 1954. Solid flux of snow-bearing air flow. Trudy Transportno-Energicheskago Instituta 4: 71-88. 1963 Tech. Translation 1102, Can. Nat. Res. Council.

~~Dyunin, A. K.~~ m 1967. Fundamentals of the mechanics of snow storms. Proc. Int. Conf. on Low Temp. Ser. Sapporo, Japan 1(2): 1065-1073.

Dyunin, A. K., and A. A. Komarov. 1954. On the construction of snow fences. Trudy Transportno-Energicheskago Instituta 4: 111-118. 1963. Tech. Translation 1103, Can. Nat. Res. Council.

Erickson, D., and H. Steppuhn. 1976. Snow trapping with unharvested strips of grain. Unpublished Report. Division of Hydrology, University of Sask., Saskatoon: 12 p.

Erickson, D., W. Lin and H. Steppuhn. 1978. Indicies for prairie runoff from snowmelt. Proc. 7th Symp. Water Studies Institute, Applied Hydrology, Saskatoon.

Evans. C. H. 1976. Role of windbreaks in Great Plains agriculture. In Shelterbelts on the Great Plains, Great Plains Agric. Council Publ. 78, pp. 212-216.

Farmer, E. E., R. W. Brown, B. E. Richardson, and P. E. Packer. 1974. Revegetation Research on the Decker Coal Mine in Southeastern Montana, U.S.D.A. Forest Service Research Paper INT-162, Intermountain Forest and Range Experiment Station.

Faulk, D. E. 1975. Summerfallow. Is there a better way to store water? Crops and Soils: 27 p.

Finn, B. J., S. J. Bourget, K. F. Nielsen, and B. K. Dow. 1966. Effects of different soil moisture tensions on grass and legume species. Can. J. Soil Sci. 41(1): 16-23.

Finney, E. A. 1934. Snow control on the highways. Michigan Engineering Experiment Station Bull. No. 57, Michigan Stage College.

Fowler, D. B. 1978. Winter cereal survival in Saskatchewan. Proc. of the 1978 Soils and Crops Workshop, Univ. of Sask. Extension Division, Publ. 390, p. 1-13.

Fowler, D. B., and L. V. Gusta. 1978. Wheat cereal production in Saskatchewan. Extension Division, University of Sask. Publ. 264; 11 p.

~~Fowler, D. B., and L. V. Gusta.~~ 1978. Winter cereal production in Saskatchewan. Agricultural Science Field Crops. Extension Division, Univ. of Saskatchewan, Saskatoon, Publ. 264, 11p.

Fowler, W. B., and H. W. Berndt. 1971. Efficiency of foliage in horizontal interception. Proc. 39th Meeting Western Snow Conf. (Billings, Montana), pp. 27-32.

3 Frank, A. B., D. G. Harris, and W. O. Willis. 1974. Windbreak influence on water relations, growth, and yield of soybeans. Crop Sci. 14: 761-765.

1 Frank, A. B., and E. J. George. 1975. Windbreaks for snow management in North Dakota. Great Plains Agric. Council, Univ. of Nebraska Exp. Stn. (Lincoln, Neb.) Publ. 73, pp. 144-154.

4 Frank~~, A. B., D. G. Harris, and W. O. Willis~~. 1976. Influence of windbreaks on crop performance and snow management in North Dakota. In Shelterbelts on Great Plains, Great Plains Agric. Council Publ. 78, 41-48.

5 Frank~~, A. B., D. G. Harris, and W. O. Willis~~. 1977. Growth and yield of spring wheat as influenced by shelter and soil water. Agron. J. 69: 903-906.

6 Frank~~, A. B., D. G. Harris, and W. O. Willis~~. 1977. Plant water relationships of spring wheat as influenced by shelter and soil water. Agron. J. 69: 906-910.

2 Frank, A. B., and W. O. Willis. 1972. Influence of windbreaks on leaf water status in spring wheat. Crop Sci. 12: 668-672.

Galbraith, A. F. 1971. The soil water regime of a short-grass prairie ecosystem. Ph.D. Dissertation, Colorado State Univ., Fort Collins, Colo,: 127 p.

Galbraith, A. F., and W. D. Striffler. 1971. The water balance of a shortgrass prairie ecosystem. Presented at Annual Meeting American Geophysical Union, Dec. 1971, San Francisco, California.

Gee, G. W., A. Bauer, and R. S. Decker. 1978. Physical analysis of overburden materials and mine land soils. Reclamation of Drastically Disturbed Lands, 677 South Segoe Road, Madison, W.I: pp. 665-686.

Geiger, R. 1961. The climate near the ground. Translated by Scripta Technia, 1965. Harvard University Press. Cambridge, Massachusetts, U.S.A.,: 611 p.

George, E. J. 1943. Effects of cultivation and number of rows on survival and growth of trees in farm windbreaks on the northern Great Plains. J. of Forestry 41: 820-828.

~~George, E. J.~~ 1971. Effects of tree windbreaks and slat barriers on wind velocity and crop yields. U.S.D.A. Prod. Res. Rept. No. 121: 23 p.

George, E. J., D. Broberg, and E. L. Worthington. 1963. Influence of various types of windbreaks on reducing wind velocities and depositing snow. J. of Forestry 61: 345-349.

Gerdel, R. W., and G. H. Strom. 1961. Wind tunnel studies with scale model simulated snow. IASH Publ. 54, General Assy. of Helsinki, pp. 80-88.

Grant, L. O., and J. Ramirez. 1975. Climatological aspects of snow on the Great Plains. Proc. Symp. Snow Management on the Great Plains, Res. Committee, Great Plains Agric. Council, Univ. of Nebraska, Agric. Exp. Sta., Lincoln, Neb., Publ. 73, pp. 187-199.

Gray, D. M., and D. I. Norum. 1967. The effect of soil moisture on infiltration as related to runoff and recharge. Proc. of Hydrology Symposium No. 6 Soil Moisture, Nov. 1967. pp. 133-153.

Gray, D. M., D. I. Norum, and J. M. Wigham. 1970. Infiltration and physics of flow of water through porus media. Section V In Handbook on the Principles of Hydrology, D. M. Gray (Editor) Publ. Canadian Nat. Committee for International Hydro. Decade and Nat. Research Council, Ottawa, Canada, pp. 5.1 - 5.58.

Greb, B. W. 1975a. Problems in monitoring snowfall at Akron, Colorado. In Snow Management on the Great Plains, Great Plains Agric. Council, (Lincoln, Nebraska), Univ. of Nebraska Agric. Exp. Sta. Publ. 73, pp. 1-12.

~~Greb, B. W.~~ 1975b. Snowfall characteristics and snowmelt storage at Akron, Colorado. In Snow Management on the Great Plains, Great Plains Agric. Council, Univ. of Nebraska Agric. Exp. Sta. Publ. 73, pp. 45-64.

~~Greb, B. W.~~ 1978. Tall wheat grass barriers boost continuously cropped forage yields. Colorado State University Experiment Station PR 78-16 Fort Collins, Col.: 3 p.

~~Greb, B. W.~~ 1979. Reducing drought affects on croplands in the west-central Great Plains, Agricultural Information Bulletin No. 420.

~~Greb, B. W.~~ 1979. Technology and wheat yields in the central Great Plains. J. of Soil and Water Conservation 34(6): 269-273.

~~Greb, B. W.~~ 1980. Why minimum tillage fallow with herbicides. Symp. on Ecofallow Feb. 1980: 5 p.

Greb, B. W., and A. L. Black. 1961a. Effects of windbreak plantings on adjacent crops. J. of Soil and Water Conservation 16: 223-227.

~~Greb, B. W., and A. L. Black~~. 1961b. New strip cropping pattern saves moisture for dryland. Crops and Soils 13(5): 23.

~~Greb, B. W., and A. L. Black~~. 1971. Vegetative barriers and artificial fences for managing snow in the central and northern plains. In Symp. on Snow and Ice in relation to Wildlife and Recreation (A. O. Haugen, Ed.), Iowa Coop. Wildlife Res. Unit, Iowa State Univ. Ames, Iowa, pp. 96-111.

Greb, B. W., D. E. Smika, and A. L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil and Water Conservation 25: 58-62.

Greb, B. W., D. E. Smika, and T. R. Welsh. 1979. Technology and wheat yields in the central Great Plains experimental station and advances. J. of Soil and Water Conservation 34(6).

Grishin, I. S. 1975. Effect of forest shelterbelts on snow distribution in the Don River Basin. Transactions of the All-Union Scientific Research Institute of Hydrometeorological Information. World Data Center (Tr. UNIIGMI MTSD) 15: 24-28. (Russian) In Soviet Hydrology: selected papers, Am. Geophysical Union, 3: 182-184 (English).

Haas, H. J., and W. O. Willis. 1962. Moisture storage and use by dryland srping wheat cropping systems. Soil Sci. Soc. Am. Proc. 26(5): 506-509.

~~Haas, H. J., and W. O. Willis~~. 1968. Conservation bench terraces in North Dakota. Trans. of the ASAE 11(3): 396-398, 402.

~~Haas, H. J., and W. O. Willis~~. 1971. Water storage and alfalfa production on level benches in the northern Plains. J. of Soil and Water Conservation 26(4): 151-154.

Haas, H. J., W. O. Willis, and G. O. Boatwright. 1966. Moisture storage and spring wheat yields on level bench terraces as influenced by contributing area cover and evaporation control. Agron. J. 58: 297-299.

Hagen, L. J., E. L. Skidmore, and J. D. Dickerson. 1972. Designing narrow strip barrier systems to control wind erosion. J. of Soil and Water Conservation (Nov.-Dec.) 27: 269-272.

Hanson, C. L., and J. K. Lewis. 1978. Winter runoff and soil water storage as affected by range condition. Proc. of the 1st International Rangeland Congress: pp. 284-287.

Hershfield, D. M. 1974. The frequency of freez-thaw cycles. J. of Applied Meteorology 13: 348-354.

Hexem, R. W., and E. O. Heady. 1978. Water production functions for irrigated agriculture. The Iowa State University Press, Ames, Iowa, U.S.A: 207 p. Analysis of Wheat Experiments, Chapter 7: pp. 106-119.

Hockensmith, R. D. and P. Harrison. 1964. Soil conservation - a world movement. In 1964 Yearbook "Farmers World", U.S. Dept. Agric., U.S. Gov. Print. Office, Washington, D.C.: 69-75.

Hofman, L., R. E. Ries, J. F. Power, and R. J. Lorenz. 1977. Effects of grazing intensity on vegetation and animal performance on reclaimed strip-mined land. Fifth Symposium on Surface Mining and Reclamation: pp. 306-310.

Hofman, L., R. E. Ries, J. F. Power, and R. J. Lorenz. 1978. Grazing reclaimed strip-mined sites. North Dakota Agricultural Experiment Station Reprint No. 935 From 1978 Farm Research 36(1): 3-5.

Hopkins, J. W. 1940. Agricultural meteorology: A statistical study of conservation of precipitation by summerfallowed soil tanks at Swift Current, Sask. Can. J. Research, C, 18: 388-400.

Hubbard, W. A., and S. Smoliak. 1953. Effect of contour dykes and furrows on short-grass prairie. J. Range Management 6(1): 55-62.

Hutchison, B. A. 1965. Snow accumulation and disspearance influenced by big sage brush. U.S. for. Serv. Res. Note RM-46. Rocky Mt. For and Range Exp. Sta: 7 p.

Janzen, P. J., N. A. Korven, G. K. Harris, and J. J. Lehane. 1960. Influence of depth of moist soil at seeding time and of seasonal rainfall on wheat yields in southwestern Saskatchewan. Research Branch, Canada Dept. of Agric. Publ. 1090: 10 p.

Johnson, W. E. 1977. Conservation tillage in Western Canada, J. of Soil and Water Conservation (Jan.- Feb.) 32: 61-64.

Kabanov, P. G. 1940. Snezhnye melioratsii (Melioration by snow) Sotsialisticheskoe Zernovoe Khozyaistvo, No. 6 cited by Shul'gin, A.M. 1957. The temperature regime of soils. Israel Program for Sci. Translations, Jerusalem 1965, Office of Tech. Services, U.S. Dept. Commerce, Washington, D.C.

Keys, C. H. 1961-1972. Unpublished Annual Reports (1963-72) Moisture conservation and utilization with particular emphasis on winter precipitation. Project 05.01.06, Saskatoon Research Station, Canada, Dept. of Agriculture.

Kibasov, P. 1955. Effectiveness of various methods of snow retention in Siberia, Zemledelie 3: 60-61. Translated from Russian, Research Branch, U.S. Forest Service, U.S. Gov. Printing Office, 5 p.

Kind, R. J. 1976. A critical examination of the requirements for model simulation of wind-induced erosion/deposition phenomena such as snow drifing. Atmospheric Environment 10:219-237.

Klein, D. A., and R. A. Sokol. 1973. Cloud seeding for snow augmentation: Land use ramifications of residual silver iodide nucleating agents. Proc. 41st Meeting Western Snow Conf. (Grand Junction); pp. 30-36

Kobayashi, Shun'ichi, and T. Ishida. 1979. Interaction between wind and snow surface. Boundary-Layer Meteorology 16: 35-47.

Komarov, A. A. 1954. Some roles on the migration and deposition of snow in western Siberia and their application to control measures. Trudy Transportno - Energetiches Koga Instituta (4) N.R.C. Tech. Translation 1094, (1963),: 89-97.

~~Komarov, A. A.~~ m 1954. Ways on increasing the efficiency of snow fences From Trudy Transportno Energeteches Kogo Instituta (4): 119-126. N.R.C. Tech. Translation 1095, (1963).

Kuźmin, P. P. 1960. Snow cover and snow reserves. Gidrometeorologicheskoe Izadtelsko, Leningrad. Translated U.S. National Sci. Found. Washington, D.C. 1963;, pp. 99-105.

Lal, R. and H. Steppuhn. 1980. Minimizing fall tillage on the Canadian Prairies - A. Review. Can. J. Agric. Engin. (in press).

Lee, L. W. 1975. Sublimation of snow turbulent atmosphere. Ph.D. Dissertation, Dept. Mechanical Engineering, Univ. of Wyoming, Laraine, Wyoming: 162 p.

Lehane, J. J., and W. J. Staple. 1953. Water retention and availability in soils related to drought resistance. Can. J. Agric. Sci. 33: 265-273.

~~Lehane, J. J., and W. J. Staple.~~ 1965. Influence of soil texture, depth of soil moisture storage, and rainfall distribution on wheat yields in southwestern Saskatchewan. Can. J. Soil Sci. 45: 207-219.

Lindwall, C., R. P. Zenter and D. T. Anderson. 1979. Conservation characteristics of minimum tillage systems. Pres. of ASAE-CSAE summer meeting Agri. Inst. of Canada.

Lull, H. W., and H. K. Orr. 1950. Induced snow drifting for water storage. J. Forestry 48: 179-181.

Lyles, L., R. L. Schrandt, and N. F. Schmeidler. 1974. How aerodynamic roughness elements control sand movement. Transactions ASAE, Ameri. Soc. Agric. Engin., 17(1): 134-139.

Lyster, B. 1976. Grass strips replace summerfallow. Country Guide, pp. 16-18.

Marks, R. T. 1967. Windbreaks and shelterbelts, Co-operative Ext. Service, Montana State College, Bozeman Bull. 318.

Marshall, J. K. 1967. The effect of shelter on the productivity of grasslands and field crops. Field Crop Abst. 20(1): 1-14.

2 ~~Martinelli, M. Jr.~~ m 1965. Accumulation of snow in alpine areas of central Colorado and means of influencing it. J. Glaciol 5: 625-636.

1 Martinelli, M. Jr. 1964. Influence of gap width below a vertical slat fence on size and location of lee drift. IASH IX Anne's 4: 48-57.

3 ~~Martinelli, M. Jr.~~ m 1965. Possibilities of snow pack management in alpine areas. Proc. of Int. Symp. on Forest Hydrology, Pennsylvania State Univ., Pergamon Press, pp. 225-231.

4 ~~Martinelli, M. Jr.~~ m 1972. Snow fences for influencing snow accumulation. Int. Symposium on the Role of Snow and Ice in Hydrology, Symp. on Measurement and Forecasting. Proc. Banff, W.M.O. UNESCO, IASH.

Matthews, G. D. 1940. Snow utilization in prairie agriculture. Canada Dept. of Agric. Research Branch, Publ. 696, Farmer's Bull. 95: 21 p.

~~Matthews, G. D.~~ m 1949. Scott Dominion Experimental Station, Progress Report, 1937-47. Canada Dept. of Agriculture, Experimental Farms Service. Edmond Cloutier, King's Printer, Ottawa, Can.: 88 p.

May, M. and R. Lang. 1971. Reclamation of strip mine spoil banks in Wyoming. Research J. 51, Agricultural Experiment Station, Univ. of Wyoming, Laramie.

McCalla, T. M., and T. J. Army. 1961. Stubble mulch farming. Adv. Agron. 13: 125-196.

McKay, G. A. 1963. Relationships between snow survey and climatological measurements. IASH Publ. 63, pp. 214-227.

McKay, G. A., and B. F. Findlay. 1971. Variation of snow resources with climate and vegetation in Canada. Proc. 39th Meeting Western Snow Conf. (Billings, Montana): pp. 17-25.

McKay, G. A., and H. A. Thompson. 1967. Snow cover in the prairie provinces. Paper #67-206 presented at CSAE-ASAE 60th Annual Meeting, Amer. Soc. Agric. Engin. ASAE Trans. 11(6): 812-815.

McMartin, W., A. B. Frank, and R. E. Heintz. 1974. Economics of shelterbelt influence on wheat yields in North Dakota. J. Soil and Water Conservation 29: 87-91.

~~McMartin, W., H. J. Haas, and W. O. Willis.~~ 1970. Economics of forage production on level benches in the Northern Plains. J. Soil & Water Conservation 25(5): 185-189.

McMartin, W., H. J. Haas, and W. O. Willis. 1970. An economic analysis of level bench systems for forage production in North Dakota. USDA Conservation Research Report. No. 14.

Mellor, M. 1965. Blowing snow. CRREL Cold Regions Science and Engineering Part III, Section A3: U.S. Army Corps of Engineers.

Michalyna, W., and R. A. Hedlin. 1961. A study of moisture storage and nitrate accumulation in soil as related to wheat yields on four cropping sequences. Can. J. of Soil Science 41(1): 5-15.

Mickelson, R. H., M. B. Cox, and K. J. Musick. 1965. Runoff water-spreading on leveled cropland. J. of Soil and Water Conservation 20: 57-60.

Neff, E. L. 1973. Water storage capacity of contour furrows in Montana. J. Range Management 26: 298-301.

Neff, E.L. and J. R. Wight. 1977. Over winter soil water recharge and herbal production as influenced by contour furrowing on Eastern Montana Rangelands. J. Range Management 30(3): 193-195.

Neff. E. L. 1980. (In press). Snow trapping by contour furrows in Southeastern Montana. Submitted for publication in J. of Range Management, Manuscript, 11 p.

Nicholaichuk, W. and D. I. Norum. 1975. Snow management on the Canadian Prairies. Proc. Symp. Snow Management on the Great Plains. Great Plains Agric. Council. Univ. of Nebraska Agri. Exp. Station (Lincoln, Nebraska) Publ. 73, pp. 118-127.

Olienyk, J. P., J. R. Snyder, M. D. Skold, and W. O. Willis. 1979. The economic benefits and costs of managing windblown snow in the northern plains of U.S. Fifth International Conference on Wind Engineering Vol. 1.

Owen, P. R. 1964. Saltation of uniform grains in air. J. Fluid Mech. 20(2): 225-242.

Papendick, R. I., and D. E. Miller. 1977. Conservation tillage in the Pacific Northwest. J. of Soil and Water Conservation (Jan.- Feb.) 32: 49-56.

Pawlowski, S. H., and A. D. Smith. 1966. Sunflowers instead of fallow. Crops and Soils 19: 6-7.

Pelton, W. L. 1967. The effect of a windbreak on wind travel, evaporation and wheat yield. Can. J. Plant Sci. 47: 209-214.

~~Pelton, W. L.~~ 1967. Wheat and climate. Proc. of the Canadian Centennial Wheat Symposium, Western Co-operative Fertilizer Ltd. Modern Press, Saskatoon, Saskatchewan, pp. 207-224.

~~Pelton, W. L.~~ 1976. Windbreak studies on Canadian Prairies. <u>In</u> Shelterbelts on the Great Plains, Great Plains Agr. Council Publ. 78; pp. 64-68.

Plate, E. J. 1971. The aerodynamics of shelterbelts. Agricultural Meteorology 8: 203-222.

Pohjakas, K., D. W. Read, and H. C. Korven. 1967. Consumptive use of water by crops at Swift Current, Sask. Canadian J. Soil Sci. 47: 131-138.

Post, F. A., and F. R. Dreibelbis. 1943. Some influence of frost penetration and microclimate on water relationships of woodland, pasture and cultivated soils. Soil Sci. Soc. Amer. Proc. 7: 95-104.

Potter, L. D., J. Longwell, and C. Mode. 1952. Shelterbelt snowdrifts. N. Dakota State Univ. Biomo. Bull. 14: 176-179.

Power, J. F., and O. L. Bennett. 1977. Protection of soil and water resources on land disturbed by mining. Proc. 2nd National Conf. on Energy/Environment, Washington, D.C.: pp. 195-201.

Power, J. F., P. L. Brown, T. J. Army, and M. G. Klages. 1961. Phosphorus response by dryland spring wheat as influenced by moisture supplies. Agron. J. 53: 106-108.

Power, J. F., R. E. Ries, and F. M. Sandoval. 1976. Use of soil materials on spoils-effects of thickness and quality. North Dakota Agricultural Exp. Station Reprint No. 891. Farm Research 34(1): 23-24.

~~Power, J. F., R. E. Ries, and F. M. Sandoval~~. 1978. Reclamation of coal-mined land in the northern Great Plains. J. of Soil and Water Conservation 33(2): 69-74.

Power, F. J., F. M. Sandoval, and R. E. Ries. 1977. Strip mining; getting the energy while keeping the environment. Crops and Soils Magazine Jan 1977; pp. 12-15.

Price, W. I. J. 1961. The effect of the characteristics of snow fences on the quality and shape of deposited snow. IASH Publ. 54 General Assy. of Helsinki 1960; pp. 89-98.

Agricultural Research Service, tr. to p.

Progress Report. 1975. Research on reclamation of strip-mined lands in the northern Great Plains. ~~Agr. Res. Service~~. U.S. Dept. of Agr. and North Dakota Agr. Res. Exp. Sta. Mandan, North Dakota.

Pugh, H. D. and W. J. Price. 1954. Snow drifting and the use of snow fences. Polar Record 7(47): 4-23.

Radok, U. 1968. Deposition and erosion of snow by the wind. CRREL. Res. Rept. 230, Hanover, New Hampshire, U.S. Army Corps of Enginers.

~~Radok, U.~~ 1977. Snow drift. J. of Glaciology 19(81): 123-139.

Rauzi, F. 1968. Pitting and inter seeding native shortgrass range-land. Research J. 17. Wyo. Agric. Exp. Sta., Univ. of Wyoming, Laramie, Wyoming. 14 p.

Rauzi, 75 here

Rauzi, F. and A. R. Kuhlman. 1961. Water intake as affected soil and vegetation on certain western South Dakota rangelands. J. Range Management 14: 267-271.

Rauzi, F. 1975. Snow management for water conservation in Wyoming. In Snow Management on the Great Plains. Great Plains Agr. Council, Univ. of Nebraska Agric. Exp. Sta. Publ. 73; pp. 180-186.

Rauzi, F. and R. L. Lang. 1957. Range pitting. What's new in Crops and Soils 9(9): 1.

Rauzi, F., L. Landers, and R. Grey. 1973. Level benches for northern plains rangelands. Montana Farmer-Stockman 60(13): 22-23.

Read, D. W. L. Unpublished data. Alternate height swathing for soil water enrichment. Swift Current Research Station. Canada Dept. of Agric. Research Branch. Swift Current, Saskatchewan.

Read, D. W. L., and F. G. Warder. 1974. Inlfuence of soil climatic factors on fertilizer response of wheat grown on stubble land in southwestern Saskatchewan. Agronomy J. 66: 245-248.

Rechard, A. 1975. A study of evaporation from a snowdrift. In Snow Management on the Great Plains. Great Plains Agricultural Council, Univ. of Nebraska Agric. Exp. Sta, Publ. 73; pp. 65-84.

Rechard, P. A. and L. W. Larson. 1971. The use of snow fences for sheilding participation gages. Proc. of 49th Meeting Western Snow Conf, (Billings, Montana); pp. 56-62.

Resource and Potential Reclamation Evaluation. Hanging Woman Creek Study Area. 1977. EMRIA. Report No. 12. U.S. Dept. of Int. Bureau of Land Management.

Richter, G. D. 1945. Snow cover its formation and properties. Publishing House U.S.S.R. Academy of Sciences, Moscow, SIPRE Trans. No. 6 1950. 113 p.

4
Ries, R. E., F. M. Sandoval, and J. F. Power. 1978. Re-establishment of grasses on land disturbed by mining in the northern Great Plains. Proc. of the First International Rangeland Congress; pp. 700-703

1
Ries, R. E., F. M. Sandoval, J. F. Power, and W. O. Willis. 1976. Perennial forage species response to sodium and magnesium sulfate in mine spoil. Fourth Symposium on Surface Mining and Reclamation, Louisville, Kentucky, Oct. 1976; pp. 173-183.

3
Ries, R. E., F. M. Sandoval, and J. F. Power. 1977. Reclamation of disturbed lands in the Lignite area of the northern Plains. Ninth Annual Lignite Symposium. Grand Forks, North Dakota, May 1977; pp. 1-18.

2
Ries, R. E., J. F. Power, and F. M. Sandoval. 1976. Potential use of supplemental irrigation for establishment of vegetation on surfaced-mined lands. North Dakota Agricultural Experiment Station Reprint. No. 892 from Farm Research 34(1): 21-22.

Rodenko, G. 1970. Protecting crop bands. Zemledeliya, No. 11 Translated by R. P. Knowles. Res. Branch, Canada Dept. Agriculture, Ottawa, 3 p.

Roots, E. F., and C. W. M. Swithinbank. 1955. Snow drifts around buildings and stores. Polar Record 7(50).

Rosenberg, N. J. 1966. Influence of snow fence and corn windbreaks on microclimate and growth of irrigated sugar beets. Agron. J. 58: 469-475.

Rylov, S. P. 1969. Snow cover evaporation in the semidesert zone of Kazakhstan. Transactions of the Kazakh Hydrometeorological Scientific Research Institute (Trudy Kaz NIGMI), No. 32,: 64-77. Translated from Russian, Soviet Hydrology: Selected Papers, Issue No. 3, (1969), pp. 258-270.

Sandoval, F. M. 1978. Deep plowing improves sodic claypan soils. North Dakota Agricultural Experimental Station. Farm Research, 35(4): 15-18.

Sandoval, F. M., J. J. Bond, J. F. Power, and W. O. Willis. 1973. Lignite mine spoils in the northern Great Plains. Characteristics and potential for reclamation. North Dakota Geol. Survey Education Series 5: 1-4.

3

Sandoval, F. M., and J. F. Power. 1977. Laboratory methods recommended for chemical analysis of mined-land spoils and overburden in western United States. U.S.D.A., Agriculture Handbook 525.

2

Sandoval, F. M., and W. L. Gould. 1978. Improvement of saline and sodium affected disturbed lands. Reclamation of Drastically Disturbed Lands 1978. Madison, W.I.; 485-501.

1

Saskatchewan Advisory Council on Soils and Agronomy. 1978. Saskatchewan Fertilizer and Cropping Practices,1978-79. Sask. Dept. of Agriculture. Extension Division, Univ. of Sask. Saskatoon, Sask. 13 p.

Saskatchewan Agricultural Services Co-ordinating Committee. 1975. Guide to farm practices in Saskatchewan 1975. Univ. of Sask., Sask. Dept. of Agric. Canada Dept. of Agric. Edited and produced by Extension Division, Univ. of Sask. 176p.

Saulmon, R. W. 1973. Snowdrift management can increase water harvesting yields. J. Soil and Water Conservation 28(3): 118-121.

Schlenhuber, A. M., and B. B. Tucker. 1967. Culture of wheat. Chapter 4, In Wheat and What Improvement, K. Quisenberry and L. Reitz (Editors) Agronomy Series No. 13, Amer. Soc. of Agronomy, Madison, Wisconsin, pp. 117-179.

tr

Schmidt~~, R. A. Jr~~. 1972. Sublimation of wind-transported snow - a model. U.S.D.A. For Serv. Res. Paper. RM-90. Rocky Mountain Forrest and Range Experiment Station, Fort Collins, Colorado.

Schmidt, R. A. Jr. 1972. A system that measures blowing snow. U.S.D.A. Forest Research Paper RM-194. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

tr

Schneider, T. R. 1962. Snowdrifts and water ice on roads. Nat. Res. Council of Canada. Tech. Transl. 1038, 200 p (Translated by D. A. Sinclair from a German report dated 1959).

Schneider, R. P. 1979. Effects of stubble height on soil moisture and N utilization. Proc. of Zero Tillage Workshop, Brandon, Man., Jan. 1979.

Scholten, H. 1979. Snow distribution behind single-row field windbreaks. J. of Forestry 77(10): 652-654.

Schuman, G. E., W. A. Berg, and J. F. Power. 1976. Management of mine wastes in the western United States. Reprinted from Land Application of Waste Materials 1976, Soil Conservation Society of America.

Shul'gin, A. M. 1957. The temperature regime of soils. (Temperaturni rezhim pohvy) GIMZ Gidrometeorologicheskoe Izdatel'stvo, Lenningrad, USSR. Translated from Russian by A. Gourevitch, Israel Program for Sci. Translations 1965, Jerusalem. U.S. Dept. Agric. and National Sci. Foundation, Office of Tech. Services, U.S. Dept. Commerce, Washington, D.C. 218p.

3 Siddoway, ~~F. H.~~ 1969. Barriers for moisture conservation and wind erosion control in the Great Plains. U.S.D.A. Agriculture Research Service, Sidney, Montana, pp. 1-19.

1 Siddoway, F. H. 1968. Annual and perennial barriers in relation to wind erosion and moisture conservation. U.S.D.A., Agricultural Research Service, Sidney, Montana, pp. 1-21.

2 Siddoway, ~~F. H.~~ 1968. Annual and perennial barriers in relation to wind erosion and moisture conservation. Workshop Proceedings - Conservation Tillage in the Great Plains, Great Plains Agricultural Council, Publ. 32; pp. 145-154.

4 Siddoway, ~~F. H.~~ 1969. Barriers for moisture conservation and wind erosion control in the Great Plains. In Proclamation of the 24th Annual Meeting on S.C.S.A. August 1969, Colorado State University, Fort Collins, pp. 62-66.

5 Siddoway, ~~F. H.~~ 1970. Barriers for wind erosion control and water conservation, J. Soil and Water Conservation 25: 180-184.

Siddoway, F. H., and A. P.Barnett. 1976. Water and wind erosion control aspects of multiple cropping. In Multiple Cropping, A.S.A. Special Publication No. 67. American Society of Agronomy Incorporated, Madison, Wisconsin, pp. 317-335.

3 Skidmore, E. L., L. J. Hagen, D. G. Naylor, and I. D. Teare. 1974. Winter wheat response to barrier induced microclimate. Agron. J. 66: 501-505.

1 Skidmore, E. L., and F. H. Siddoway. 1978. Crop residue requirements to control wind erosion. Crop Residue Management Systems Publ. 31, pp. 17-31, (677 S. Segoe Road, Madison, Wisconsin 53711).

2 Skidmore, E. L., and I. D. Teare. 1975. Wind barriers most beneficial at intermediate stress. Crop Sci. 15: 443-445.

Smika, D. E., and C. J. Whitfield. 1966. Effect of standing wheat stubble on storage of winter precipitation. J. Soil and Water Conservation, 21: 138-141.

Snyder, J. R., and M. D. Skold. 1978. The economics of snow management. Presented at the 1978 Western Agricultural Economics Association Meeting, Bozeman, Montana, <u>In</u> the Western Agricultural Economics Journal.

Snyder, J. R., M. D. Skold, and W. O. Willis. 1980. Economics of snow management for agriculture in the Great Plains. J. Soil and Water Conservation 35(1), 21-24.

Soiseth, R. J., J. R. Wight, and J. K. Aase. 1974. Improvement of panspot (Solonetzic) range sites by contour furrowing. J. Range Management 27: 107-110.

Sonder, L. W., and H. P. Alley. 1961. Soil moisture retention and snow holding capacity as affected by the chemical control of big sagebrush (Artemisia Tridentata Nutt). Weeds 9:27-35

Sonmor, L. G. 1955-58. Annual Reports, Irrigation Substation, Vauxhall, Alberta. Lethbridge Research Station, Can. Dept. of Agric., Lethbridge, Alberta.

~~Sonmor, L. G.~~ 1963. Seasonal consumptive use of water by crops grown in southern Alberta, and its relationship to evaporation. Can. J. Soil Sci. 43: 287-297.

Stanton, C. R. 1966. Preliminary investigation of snow accumulation and melting in forested and cut-over areas of the Crowsnest forest. 34th Meeting Western Snow Conf., (Seattle, Washington), pp. 7-11.

Staple, W. J., and J. J. Lehane. 1952. The conservation of soil moisture in southern Saskatchewan. Scientific Agriculture, 32: 36-47.

~~Staple, W. J., and J. J. Lehane~~. 1954. Weather conditions influencing wheat yields in tank and field plots. Can. J. of Agric. Sci., 34: 552-564.

~~Staple, W. J., and J. J. Lehane~~. 1954. Wheat yield and use of moisture on substations in southern Saskatchewan. Can. J. Agric. Sci., 34: 460-468.

~~Staple, W. J., and J. J. Lehane~~. 1955. The influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield. Can. J. Agric. Sci., 35: 440-453.

Staple, W. J., J. J. Lehane, and A. Wenhardt. 1960. Conservation of soil moisture from fall and winter precipitation. Can. J. of Soil Sci. 40: 80-88.

Steppuhn, H., and D. E. L. Erickson. 1978. Water conservation for wheat production in the brown and dark brown soil zones. Presented at the Wheat Prod. Systems - Seminar Series, Agric. Canada Res. Station, Swift Current, Sask.

Steppuhn, H., and D. M. Gray. 1977. Potential sublimation on the Canadian Prairies. Unpublished Report. Division of Hydrology, Univ. of Saskatchewan, Saskatoon, Sask.

Steppuhn, H., and G. E. Dyck. 1974. Estimating true basin snowcover. Proc. of Symp. on Advanced Concepts and Techniques in the Study of Snow and Ice Resources. U. S. Nat. Academy of Sciences, Washington, D. C., pp. 314-324.

tr.

Stoeckeler, J. H. 1963. Shelterbelts and their effects on crop yields in the Great Plains. J. of Soil and Water Conservation (July-August) 18: 139-144.

Stoeckeler, J. H., and C. G. Bates. 1939. Shelterbelts - the advantages of porous soils. J. Forestry, 37: 207-221.

Stoeckeler, J. H., and E. J. Dortignac. 1941. Snowdrifts as a factor in growth and longevity of shelterbelts in the Great Plains. Ecology 22: 117-124.

Stoliarov, V. I. 1976. Slitting - an effective method of preventing runoff of snow water and increasing moisture accumulation in soils on slopes. Sib. Vestn S-Kh Nauk. 1:22-28.

Sturges, D. L. 1975. Hydrologic relations on undisturbed and converted big sage brush lands. The Status of our Knowledge. USDA Forest Service Research Paper RM-140, pp. 1-23.

Sturges~~, D. L.~~ 1977. Snow accumulation and melt in sprayed and undisturbed big sagebrush vegetation. USDA For Ser. Res. Note RM-348, 6 p.

Sturges~~, D. L.~~ 1977b. Soil moisture response to spraying big sagebrush. A seven-year study and literature interpretation. USDA For Ser. Res. Pap. RM-188, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colorado.

~~Sturges, D. L.~~ 1979. Boundary Ridge Snow Management Project. Unpublished Report on a co-operative snow management project between the U.S. Bur. of Land Management, Poison Creek Grazing Allotment, Wyoming, and the Rocky Mountain Forest and Range Experiment Station.

Swank, G. W., and R. W. Booth. 1970. Snow fencing to redistribute snow accumulation. J. Soil and Water Conservation 25: 197-198.

Swanson, R. H., and D. R. Stevenson. 1971. Managing snow accumulation and melt under leafless aspen to enhance watershed value, Proc. 39th Ann. Western Snow Conference, Billings, Montana, April 1971: 63-76.

Tabler, R. D. 1968. Physical and economic design criteria for induced snow accumulation projects. Water Resources Res. 4: 513-519.

Tabler~~, R. D.~~ 1971a. A watershed test of snow fences to increase snow accumulation and water yield-first results, Proc. of 39th Meeting Western Snow Conf. (April, 1971), pp. 50-62.

Tabler~~, R. D.~~ 1971b. Snow fences for watershed management. Proc. Snow and Ice in relation to Wildlife and Recreation Symp. (Ames, Iowa, Feb. 1971), pp. 116-121.

Out

~~Tabler, R. D~~. 1972. Evaluation of the first year performance of the interstate - 80 snow fence system, prepared for the Wyoming Highway Dept. USDA Forest Service. 84 pp.

~~Tabler, R. D~~. 1973. Evaporation losses of wind blown snow, and the potential for recovery. Proc. 41st Western Snow Conf., Grand Junction, Colorado, April 1973, pp. 75-79.

~~Tabler, R. D.~~ 1974. New engineering criteria for snowfence systems. Transp. Res. Board (NRC) Record 506: 65-78.

~~Tabler, R. D~~. 1975. Estimating the transport and evaporation of blowing snow. Snow Management on the Great Plains. Great Plains Agric. Council. Univ. of Nebraska Agric. Exp. Sta. Publ. 73, pp. 85-104.

~~Tabler, R. D.~~ 1975. Predicting profiles of snowdrifts in topographic catchments. Proc. 43rd Meeting Western Snow Conf., pp. 87-97.

~~Tabler, R.~~ D. 1976. Preliminary design criteria for snow fences on Alaska's north scope. Rocky Mountain Forest and Range Exp. Stn., USDA Forest Service, June 9, 1976, 30 p.

~~Tabler, R. D~~. 1979. Geometry and density of drifts formed by snow fences. Symp. on Snow in Motion, USDA Forest Ser. Fort Collins, Colorado, 18 p.

~~Tabler, R.~~ D. 1979. Self-similarity of wind profiles in blowing snow allows outdoor modeling. Symp. on Snow in Motion, USDA Forest Ser., 18 p.

Tabler, R. ~~D~~. 1979. Snow control with road design and snow fences. Pres. at snow control workshop, Rocky Mountain Forest and Range Exp. Station and Wyoming Highway Dept. Laramie, Wyo. April 4-5,: 10 p with Appendix and A and B.

Tabler, R. D., and K. L. Johnson. 1971. Snow fences for watershed management. Proc. Symp. on Snow and Ice in Relation to Wildlife and Recreation (Ames, Iowa), pp. 116-121.

Tabler, R. D., and R. A. Schmidt. 1972. Weather conditions that determine snow transport distances at a site in Wyoming. Proc. Int. Symp. on the Role of Snow and Ice in Hydrology. UNESCO/WMO/IAHS, pp. 118-127.

Tabler, R. D., and D. L. Veal. 1971. Effect of snow fence height on wind speed. Bull. of the Int. Association of Scientific Hydrology. XVI, 4(12): 49-56.

Thorpe, A. D., and B. J. Mason. 1966. The evaporation of ice spheres and ice crystals. Bull. of Applied Physics, 17: 541-548.

Thysell, J. C. 1938. Conservation and use of soil moisture at Mandan, North Dakota, USDA Tech. Bull. 617.

Toy, T. J. 1979. Potential evaportranspiration and surface mine rehabilitation in the Powder River Basin, Wyoming, Montana. J. of Range Management 32(4): 312-316.

Unger, P. W., R. R. Allen, and A. F. Weise. 1971. Tillage and herbicides for surface residue maintenance, weed control and water conservation. J. of Soil and Water Conservation 26: pp. 147-150.

U. S. National Academy of Sciences. 1970. "Snow Research and Control", Appendix C in Polar Research - A Survey, (Washington, D.C.), pp. 97-102.

Van Haveren, B. P. 1974. Soil water phenomena of a short grass prairie site. Nat. Resources Ecology Lab., IBP - Grassland Biome, Colorado State Univ. Tech. Report. No. 247, 175 p.

Van Haveren, B. P., and W. D. Striffler. 1976. Snow melt recharge on a short grass prairie site. Proc. 44th Meeting Western Snow Conference, April 1976, (Calgary, Alberta), pp. 56-62.

Vasil'yev, I. M. 1956. Wintering of plants. Translated from Russian by American Institute of Biological Sciences, 1961, Washington, D.C., 300 p.

Warnick, C. C. 1951. Laboratory and field experiments with snow gauges in Idaho, Proc. 19th Meeting Western Snow Conference, pp. 57-68.

tr,

Weisbecker, L. W. (compiled by). 1974. The impacts of snow enhancement. Technological assessment of winter orographic snow pack augmentation in upper Colorado River Basin. Univ. of Oklahoma Press, Norman, Okla., prepared for Nat. Sci. Found.,: 624 p.

Whitfield, C. J., and C. L. Fly. 1939. Vegetational changes as a result of furrowing pasture and rangelands. J. Ameri. Soc. Agron., 31: 413-417.

insert here

Wight, J. R., E. L. Neff, and F. H. Siddoway. 1975. Snow management in eastern Montana rangelands. Proc. Symp. Snow Management on the Great Plains. Great Plains Agric. Council and Univ. of Nebraska Agric. Exp. Station, Publ. 73, (Lincoln, Nebraska), pp. 138-143.

Wight, J. R., E. L. Neff, and R. J. Soiseth. 1978. Vegetation response to contour furrowing. J. Range Management 31(2): 97-101.

tr, to prev page

Wight, J. R., and F. H. Siddoway. 1972. Improving precipitation - use efficiency on rangeland by surface modification. J. Soil and Water Conservation 27: 170-174.

Wight, J. R., and L. M. White. 1974. Interseeding and pitting on a sandy range site in eastern Montana. J. Range Management 27(3): 206-210.

Willen, D. W., C. A. Shumway, and J. E. Reid. 1971. Simulation of daily snow water equivalent and melt. Proc. 39th Meeting Western Snow Conference, pp. 1-8.

Willis, W. O. 1975. Soil water, management, and other factors that affect crop production. I.A.E.A., pp. 192: 1-17.

~~Willis, W. O.~~ 1979. Snow on the Great Plains. Proc. Meeting/Workshop. Modeling of snow cover runoff (S. Colbeck and M. Ray, Eds.), U.S. Army Cold Regions Res. and Engineering Lab., Amer. Geophysical Union and Amer. Meteorological Society, pp. 56-62.

Willis, W. O., and C. W. Carlson. 1961. Winter precipitation - too much is lost. North Dakota Farm Res. Brmo. Bull. 22: 14-15.

~~Willis, W. O., and C. W. Carlson.~~ 1962. Conservation of winter precipitation in the northern plains. J. of Soil and Water Conservation (May-June) 17: 122-123.

insert here

Willis, W. O., C. W. Carlson, J. Alessi, and H. J. Haas. 1961. Depth of freezing and spring runoff as related to fall soil moisture level. Can. J. of Soil Sci. 41: 115-123.

4

tr, to previous page

1 Willis, W. O., and A. B. Frank. 1975. Water Conservation by Snow Management in North Dakota. Proc. Symp. Snow Management on the Great Plains, Great Plains Agric. Council and Univ. of Nebraska Agric. Exp. Station, Lincoln, Nebraska, Publ. 73, pp. 155-162.

7 Willis, W. O., A. B. Frank, E. J. George, and H. J. Haas. 1976. Soil water extraction by, and growth of, multi-row windbreaks, Proc. Shelterbelts on the Great Plains, Great Plains Agric. Council Publ. 78, pp. 87-92.

2 Willis, W. O., and H. J. Haas. 1969. Water conservation over winter in the northern Great Plains. J. Soil and Water Conservation 24: 184-186.

3 ~~Willis, W. O., and H. J. Haas.~~ 1971. Snow and snowmelt management with level benches, small grain stubble and windbreaks. Proc. Symp. Snow and Ice in Relation to Wildlife and Recreation, Iowa Co-operative Wildlife Unit, Iowa State Univ., Ames, Iowa, U.S.A.,: pp. 86-95.

6 Willis, W. O., H. J. Haas, and C. W. Carlson. 1969. Snow pack runoff as affected by stubble height. Soil Sci. 107(4): 256-259.

5 Willis, W. O., H. L. Parkinson, C. W. Carlson, and H. J. Haas. 1964. Water table changes and soil moisture loss under frozen conditions. Soil Sci. 98: 244-248.

8 Willis, W. O., M. D. Skold, and J. R. Snyder. (In press). Economics of snow management for dryland agriculture in the Great Plains. Contributions from USDA Science and Education Administration, Agricultural Research and Colorado State University.

Woodruff, N. P. 1954. Shelterbelt and surface barrier effects on wind velocities, evaporation, house heating, snow drifting, Kansas Agric. Exp. Stn., Tech. Bull. 77, Kansas State College, Manhattan, Kansas.

Woodruff, N. P., L. Lyles, F. H. Siddoway, and D. W. Fryrear. 1977. How to control wind erosion, Agricultural Information Bull. 354 USDA, pp. 1-23.

Wueben, J. L. 1978. A hydraulic model investigation of blowing snow. Cold Regions Research and Engineering Lab., U.S. Army Corps of Engineers, Hanover, New Hampshire, CRREL Report (78-16), 20 p.

Ylimaki, A. 1962. The effect of snow cover on temperature conditions in the soil and over-wintering of field crops. Annales Agriculture Finniae, 1: 192-216 (Seria Phytopathologia No. 3, Sarja Kasvitaudt N:03).

Zaylaskie, J. J. 1967. Modified windbreaks control wind, snowdrift. North Dakota Farm Res. 24.9: 4-6.

Zingg, A. W., and V. L. Hauser. 1959. Terrace benching to save potential runoff for semiarid land. Agronomy J., 51: 289-292.